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Utsu et al.

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[54] TRANSPONDER FOR VEHICLE IDENTIFICATION DEVICE

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[22] Filed: Jun. 4, 1993

Related U.S. Application Data

[63] Continuation of Ser. No. 588,994, Sep. 26, 1990, abandoned.

[30] Foreign Application Priority Data

Sep. 27, 1989 [JP] Japan 1-251626

[51] Int. Cl.^{5} G01S 13/80

[52] U.S. Cl. 342/51; 342/44

[58] Field of Search 342/44, 42, 43, 46, 342/50, 51

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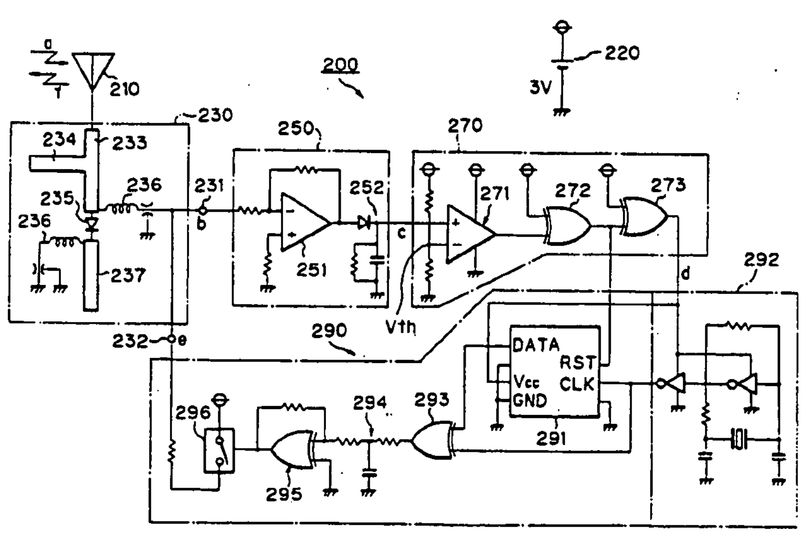
Primary Examiner—John B. Sotomayor
Attorney, Agent, or Firm—Cushman, Darby & Cushman

[57] ABSTRACT

The invention relates to a transponder for a vehicle identification device in which a radio wave including vehicle information returned from transponders provided in a vehicle is received by an interrogator. The vehicle transponder receives a query radio wave and uses a detection device to generate a previously memorized coded signal train in response to a received wave. The coded signal train varies an amount of bias voltage of the detection device so that a reflection coefficient of the detection device is varied to modulate the reflection wave of the query radio wave and the modulated wave is transmitted back to the interrogator.

10 Claims, 7 Drawing Sheets



07/28/2004, EAST Version: 1.4.1

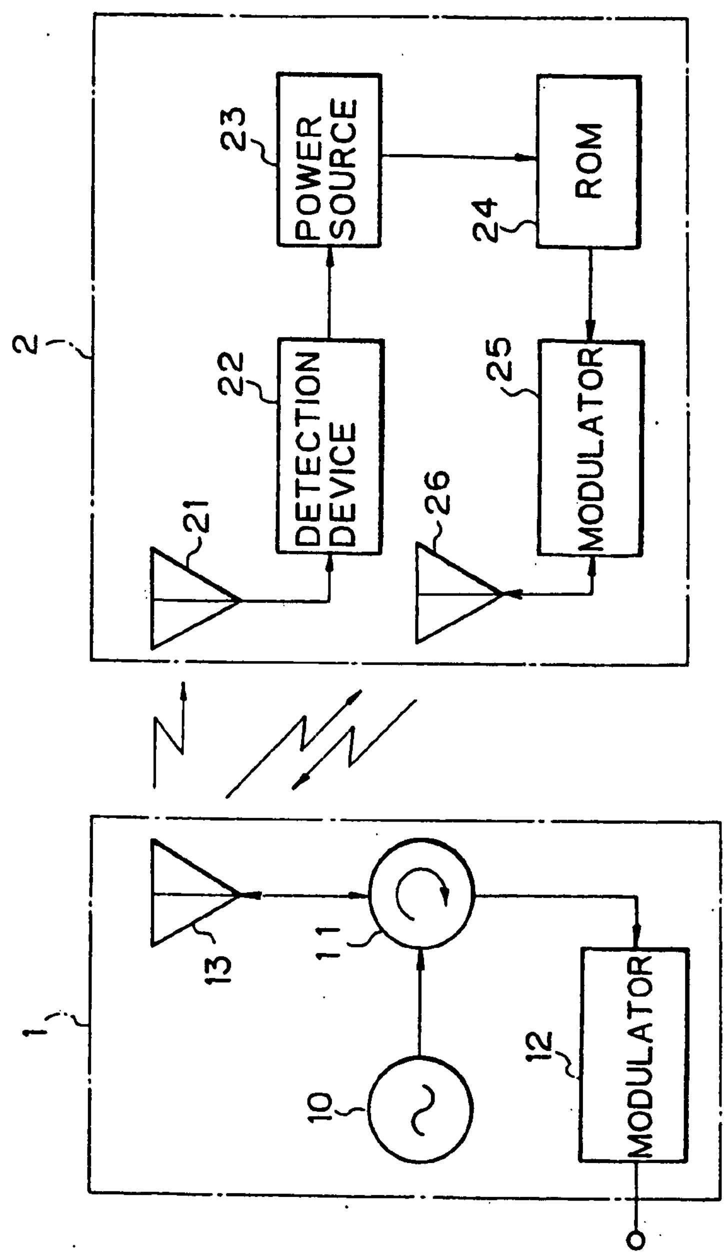
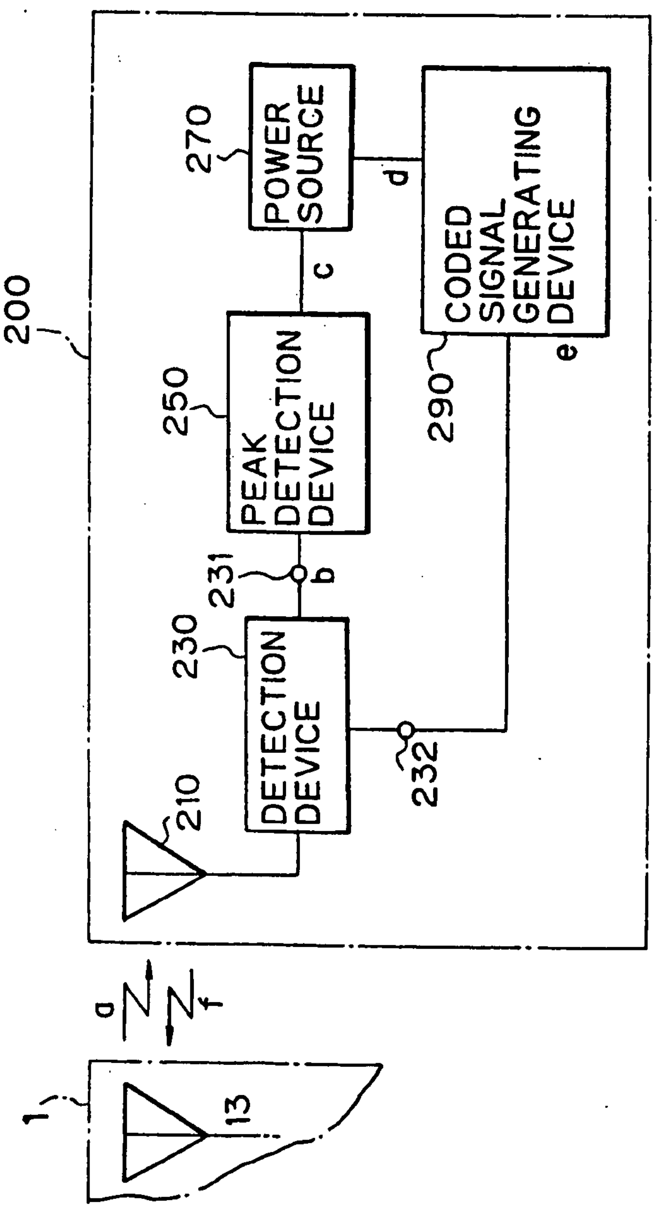


Fig. 1
PRIOR ART

Fig. 2


200
270
POWER SOURCE
c
d
250
PEAK DETECTION DEVICE
CODED SIGNAL GENERATING DEVICE
290
e
231
b
230
DETECTION DEVICE
232
210
a
f
1
13

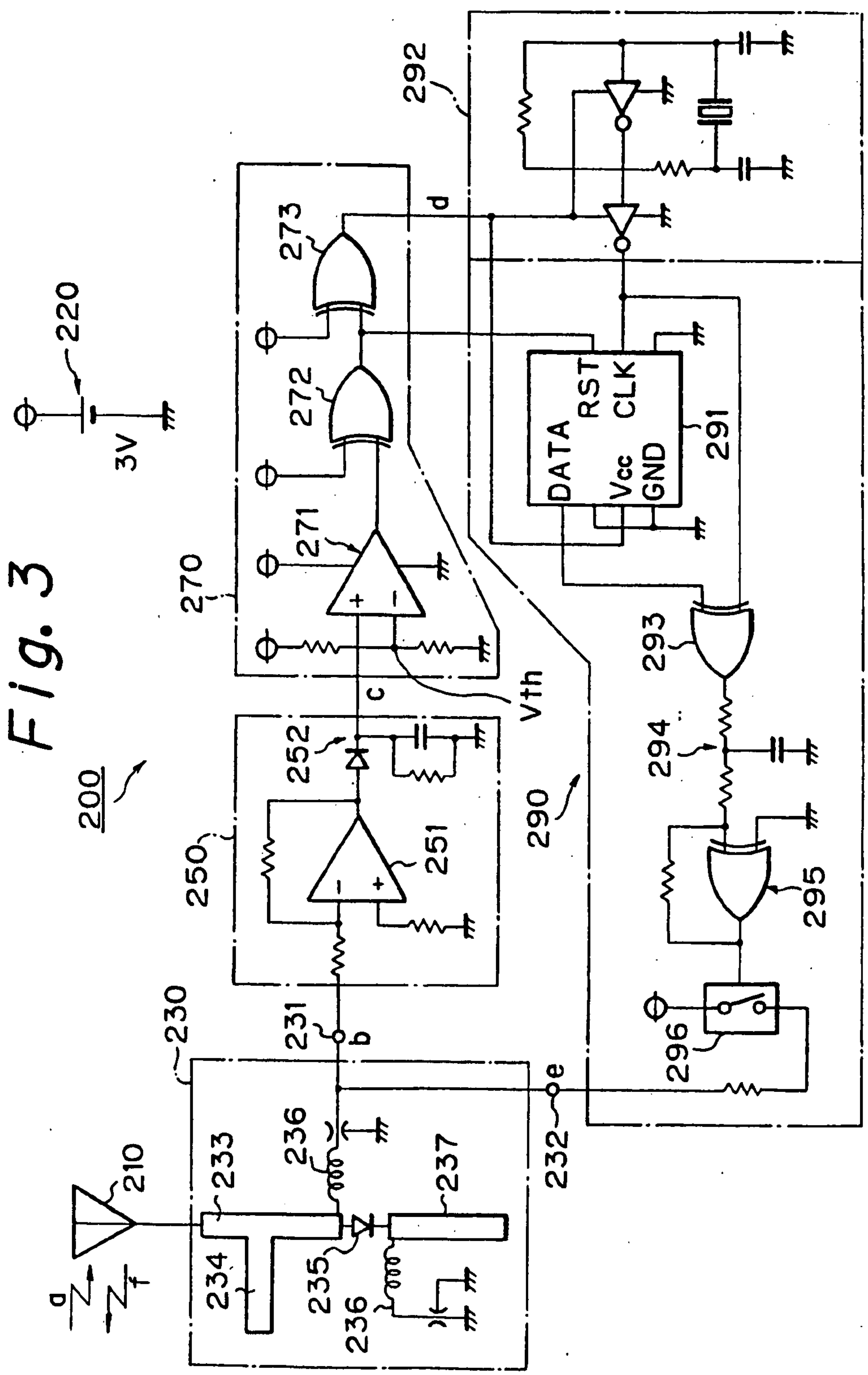
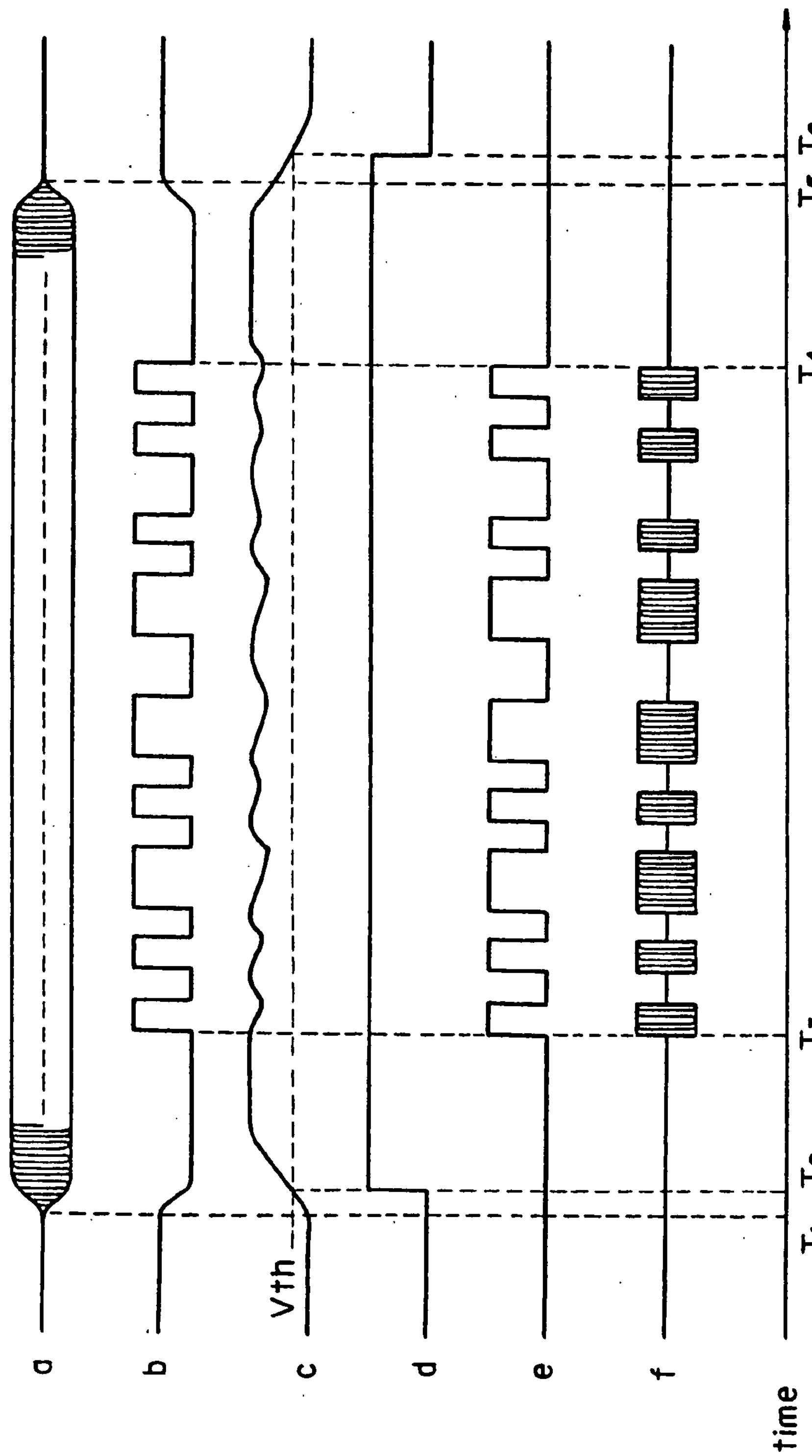

200
210
220
3V
230
231
232
233
234
235
236
237
250
251
252
270
271
272
273
290
291
292
293
294
295
296
DATA
RST
CLK
Vcc
GND
Vth
a
b
c
d
e
f

Fig. 3

Fig. 4



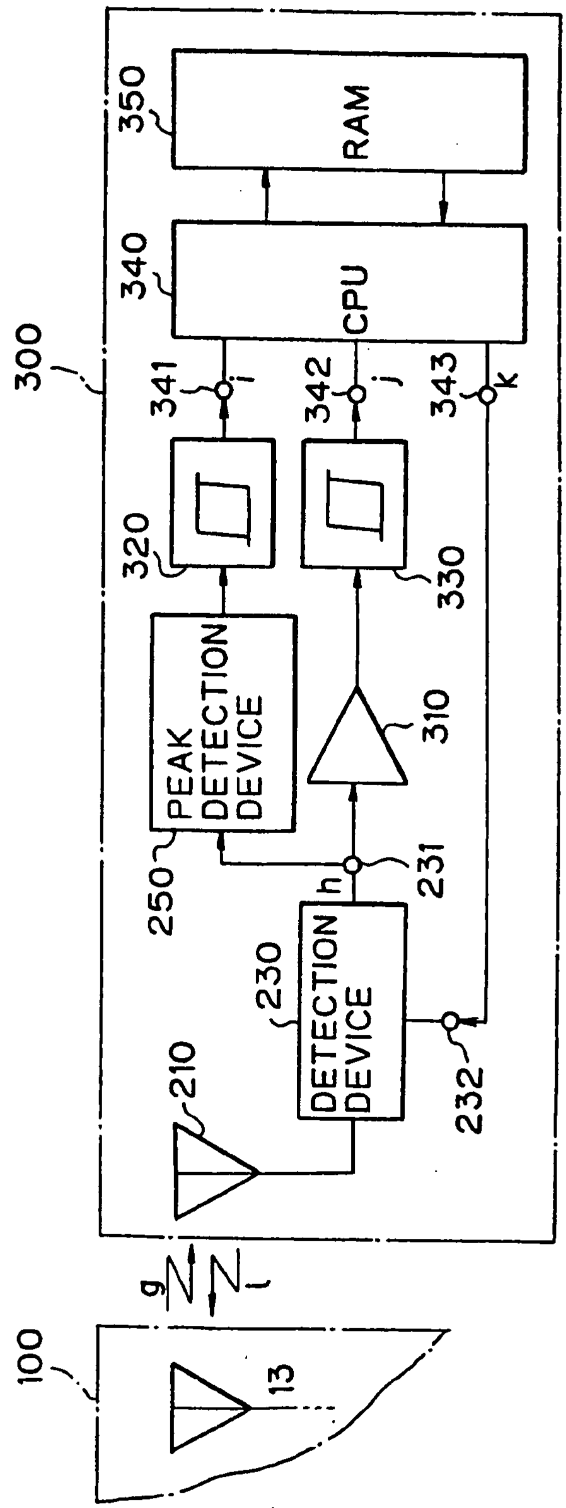

RAM
CPU
PEAK DETECTION DEVICE
DETECTION DEVICE
300
350
340
341
342
343
320
330
310
250
230
231
232
210
100
13
i
j
k
h
g
l

Fig. 5

Fig. 6

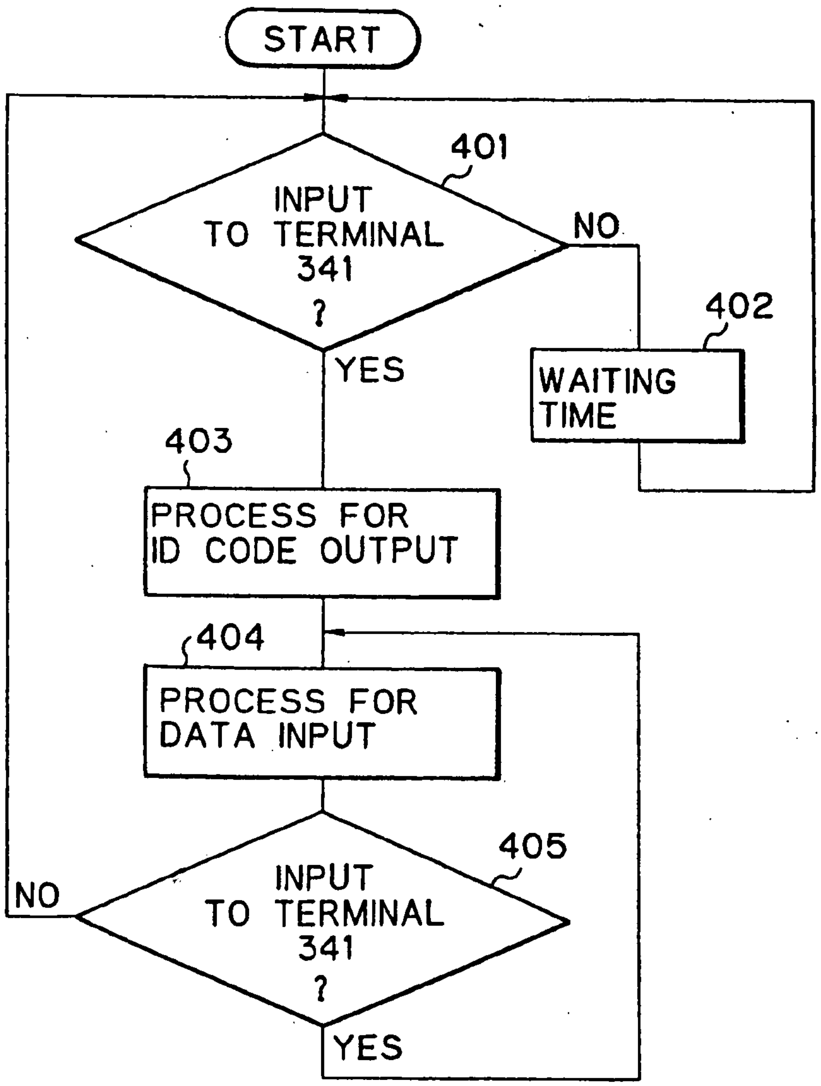
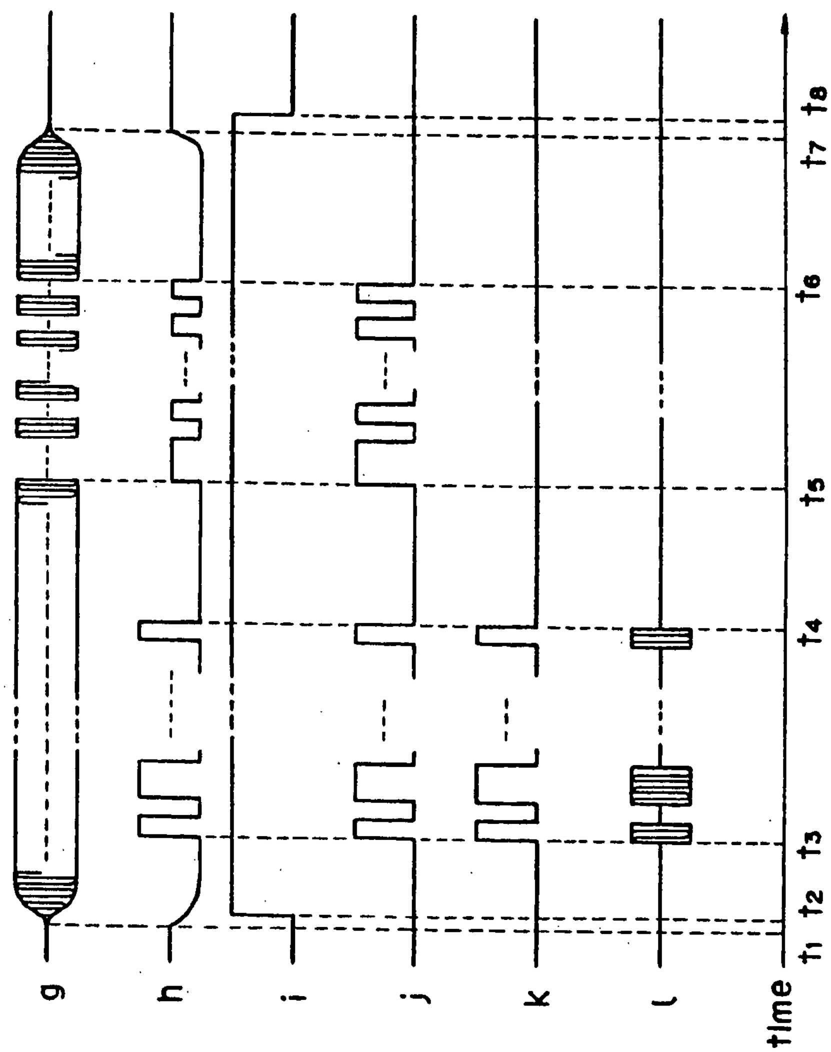

START
401
INPUT TO TERMINAL 341 ?
NO
402
WAITING TIME
YES
403
PROCESS FOR ID CODE OUTPUT
404
PROCESS FOR DATA INPUT
405
INPUT TO TERMINAL 341 ?
NO
YES

Fig. 7



TRANSPONDER FOR VEHICLE IDENTIFICATION DEVICE

This is a continuation of application Ser. No. 07/588,994, filed on Sep. 26, 1990, which was abandoned upon the filing hereof.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a transponder in a vehicle device on the vehicle side identification.

2. Description of the Related Art

As a conventional vehicle identification device, devices such as shown in Japanese Unexamined Utility Model Publication No. 57-159180 or Japanese Unexamined Patent Publication No. 61-201179 are well known.

In these conventional vehicle identification devices, a transponder, also called an identification tag (tag in short) modulates an unmodulated microwave transmitted from an interrogator with an ID code stored in a memory means provided in the tag and returns the modulated microwave back to the interrogator. Information inherent to a certain vehicle on which the tag is mounted is thus reported to the interrogator.

One example of the construction of a conventional vehicle identification device is shown in FIG. 1.

In FIG. 1, the conventional vehicle identification device is provided with an interrogator 1 and a tag 2. The interrogator 1 transmits an unmodulated microwave generated from a microwave oscillator 10 from an antenna 13 through a circulator 11 and demodulates the microwave received by the antenna 13 utilizing a demodulator 12 to output the demodulated microwave.

The tag 2 is designed so as to enable an electric power source 23 for a modulator 25 and a ROM 24 to be switched ON only when the unmodulated microwave transmitted from the interrogator 1 is received by the antenna 21 and detected by a detector 22, in order to prevent excess consumption of electric power of a battery.

Thus, when the electric power source 23 is ON, the tag modulates the microwave thus received in response to a coded signal stored in the ROM 24 and transmits back the modulated microwave to the interrogator 1.

In the conventional technology as shown in FIG. 1, the tag is generally required to have a detecting antenna 21, a detector 22, and an electric power source controlling circuit 23, in addition to a modulating antenna 26 and a modulator 25, to perform its inherent operation.

Among these components, the detecting antenna 21 modulating antenna 26 and the detector 22 and modulator 25 constitute distributed constant circuits. Therefore, it is difficult to minimize the size thereof to that of another lumped constant circuit.

Especially, the antennas 21 and 26 are required to have at least a predetermined area to obtain a gain high enough to operate the tag normally and thus the area occupied by these antennas is the largest among those of other components in the tag.

Accordingly, it is difficult to minimize the size of the tag remarkably in a conventional tag having two antennas.

The object of the present invention is to overcome these technological problems in the conventional tag and to provide a tag with a minimized size.

SUMMARY OF THE INVENTION

To attain the object of the present invention, there is provided transponder for a vehicle identification device in which a radio wave including vehicle information returned from a transponder provided in each vehicle is received by an interrogator. Each vehicle transponder comprises an antenna for receiving a query radio wave transmitted from the interrogator, a detection device for detecting the query radio wave received by the antenna, a coded signal generating means for generating a coded signal train, previously stored, in response to a detection output from the detection device, and a bias controlling means for varying an amount of the bias of the detection device in accordance with the coded signal train output from the coded signal generating means and for varying a reflection coefficient of the detection device in accordance with the coded signal train so that the coded signal train is returned to the interrogator as a responding radio wave generated by modulating the reflected wave of the query radio wave.

The transponder for a vehicle identification device of the present invention receives and detects a query radio wave and generates a previously memorized coded signal train in response to the detection output.

After that, this coded signal train causes a change in the reflection coefficient of the detector, whereby the reflected wave of the query radio wave is transmitted back to the interrogator as a modulated radio wave.

The present invention is characterized in that the reflection coefficient is varied by varying the amount of bias of the detection device.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a construction of a conventional vehicle identification device;

FIG. 2 is a block diagram of a construction of one embodiment of a vehicle identification device of the present invention;

FIG. 3 shows a circuit used in the embodiment shown in FIG. 2;

FIG. 4 is a timing chart illustrating an operation of the embodiment shown in FIG. 2;

FIG. 5 is a block diagram of a construction of another embodiment of a vehicle identification device of the present invention;

FIG. 6 is a flow chart of the operation of the other embodiment shown in FIG. 5; and

FIG. 7 is a time chart of the operation of the other embodiment shown in FIG. 5;

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiments of the present invention will be explained with reference to the attached drawings hereunder.

As stated above, the basic technological feature of the present invention is that a transponder, i.e., tag, comprising an antenna 210 for receiving a query radio wave transmitted from the interrogator 1, a detection device 230 for detecting the query radio wave received by the antenna 210, a coded signal generating means 290 for generating a coded signal train, previously stored, in response to a detection output generated from the detection device 230, and a bias controlling means 232 for varying an amount of the bias of the detection device in accordance with the coded signal train output from the coded signal generating means 290 and for varying a

reflection coefficient of the detection device 230 in accordance with the coded signal train so that the coded signal train is returned to the interrogator 1 as a responding radio wave generated by modulating the reflected wave of the query radio wave.

This feature is embodied in the block diagram of FIG. 2, in which a tag 200 is provided with an antenna 210 which is commonly used for detecting and modulating a radio wave, a detection device 230 having an output terminal 321 from which a negative voltage is output when a microwave is detected and a bias input terminal 232, an electric power source controlling circuit 270 which can supply electric power to a coded signal generating means 290 when an input voltage exceeds a certain threshold voltage Vth thereof, and a coded signal generating means 290 generating a modulating signal in response to an ID code previously stored in a certain memory.

In this embodiment, the coded signal generating means 290 also serves as a bias controlling means connected to the bias terminal 232.

FIG. 3 shows the detailed circuit of one embodiment of a tag of the present invention. In that figure, the antenna 210 and the detection device 230 constitute a distributed constant circuit of a micro strip line.

The detection device 230 is provided with a 50Ω line 233, a stub 234 for matching an input signal, a Schottky barrier diode 235, a low-pass filter for generating a DC bias and for outputting a detection output, and a short termination for a high frequency wave having a wavelength of $\lambda/4$ (wherein λ is a line wavelength).

In this embodiment, a modulating function is given to a detection device, which is conventionally used only for detecting purposes, without changing the basic construction of the detection device itself.

Note that, in this embodiment, the bias current to the Schottky barrier diode 235 is changed by applying the modulated signal to the bias input terminal 232, whereby a reflection microwave is modulated by the amplitude modulation method utilizing variation of the reflection coefficient of the detection diode 235 in response to the variation of the bias current.

According to this embodiment, since the detection device 230 has a modulating function, a modulator and a modulating antenna, necessary components in a conventional detection device, can be omitted, so the size of the distributed constant circuit of the tag can be reduced to a half of that in a conventional detection device.

While, in this embodiment, since a modulating signal should be superimposed on a detection output signal when the modulating operation is carried out, a circuit for eliminating the modulated signal component from the detection output is required.

Toward this end, in this embodiment, a peak detecting means 250 comprising an inverting amplifier 251 and an envelope detection circuit 252 is provided in the tag.

When the output voltage of the peak detecting means 250 exceeds a threshold voltage Vth of a comparator 271 in the electric power source controlling means 270, electric power is supplied to a ROM 291 and clock oscillator 292, whereby transmission of the ID code is started.

In this situation, the electric power is input to an input terminal Vcc of the ROM 291 through a gate circuit 273, whereby the ROM 291 starts to transmit the ID code therefrom in response to a reset signal input to a terminal RST through a gate circuit 272.

The ID code is output from a terminal DATA in synchronization with a clock signal input to a terminal CLK.

The waveform of the ID code thus output therefrom is shaped through a gate circuit 293, a low-pass filter 294, and an amplifier 295 and then input to a bias terminal 232 of the detection device through a switching circuit 296.

The switching circuit 296 is provided to obtain a necessary bias current for the detecting diode 235.

In this embodiment, the ID code, i.e., a coded signal, may be used in a form of a coded signal train or the like and the coded signal train is previously prepared in accordance with an inherent coded signal of the transponder mounted on the individual vehicle.

The operation of this embodiment will be explained with reference to FIGS. 2 to 4 hereunder.

FIG. 4 is a timing chart indicating the signal level of each component used in this embodiment as shown in FIGS. 2 and 3.

In FIG. 4, a denotes an unmodulated microwave transmitted from the interrogator and b denotes a detection output of the detection device 230.

Further, c, d, and e denote an output of the peak detector 250, an output of the electric power source controlling circuit 270, and a modulated signal modulated by the ID code output from the ROM 291, respectively.

f denotes a modulated microwave transmitted back from the tag to the interrogator.

In that figure, when a tag 200 comes into a identifying area of the interrogator 1 and receives an unmodulated microwave at a time T_1, a negative voltage as shown in the waveform b is output from the detection output terminal 231.

When a signal c generated by invertedly amplifying the detection output b exceeds a certain threshold voltage level at a time T_2, the output of the electric power source controlling means 270 is turned ON, whereby the ROM 291 and the clock generating circuit 292 start to operate.

After the ROM 291 outputs the ID code at a time T_3, the reflection coefficient of the detection diode 235 is varied and thus the reflected wave f is modulated by an amplitude modulating method.

In this system, although the detection output signal b is also varied due to the variation of the bias of the detection diode 235, the variation can be absorbed by a peak detecting circuit 250 and no adverse effect is given to the electric power signal d.

The modulating operation is ended at the time T_4.

Then, after the tag 200 gets out from the identifying area at the time T_5 and a predetermined time for keeping the signal of the peak detection device 250 has passed at the time T_6, the electric power source is turned OFF to result in a waiting condition for the next detecting operation.

As explained above, in this embodiment, a microwave received by the antenna 210 is modulated by amplitude modulation in two conditions, i.e., a reflecting condition and an absorbing condition, utilizing variation of the reflection coefficient caused by the variation of the bias current in the detection diode 235.

Then, the thus absorbed microwave is detected and used for maintaining the power source.

Accordingly, in this embodiment, a function equivalent to that of a conventional tag can be realized by a microwave circuit having only one antenna and one diode and thereby a cheaper tag having a smaller size compared with that of a conventional one can be produced.

In this embodiment shown in FIG. 3, although a Schottky barrier diode is used as the detection diode 235, any kind of device having both a detecting function and a function by which the reflection coefficient is varied in response to a bias current, for example, a transistor, can be used to constitute a tag having the same function as explained above.

Instead of using the peak detection device 250, the electric power source controlling circuit 270, and the coded signal generating means 290, in order to obtain a tag a having the same function as explained above, a computer circuit, i.e., CPU circuit, can be used, in which a certain software program under which the circuit is operated for a predetermined time duration after a detection signal is input therein for outputting the ID code associated therewith.

In the embodiment of the present invention as explained above, only the ID code is read out from the tag, but the present invention can be applied to a tag having a function to write signals therein.

FIG. 5 is a block diagram of another embodiment of the present invention.

In that figure, components common to FIG. 2 carry the same reference numerals as used in FIG. 2, and the explanations thereof are omitted.

In FIG. 5, an interrogator 100 has a function for modulating a microwave with amplitude modulation and transmitting the thus modulated signal.

While, a tag 300 is provided with an AC amplifier 310, comparators 320 and 330, CPU 340, and a RAM 350.

The CPU 340 is further provided with a switching control terminal 341 for switching an operation mode, an input terminal 342 for inputting write data thereinto, and an output terminal 343 for outputting a modulated signal.

The CPU 340 has a program as shown in FIG. 6, in which when the terminal 341 is turned OFF, the operation mode thereof is switched to a waiting mode (power saving mode) carried out along steps 401 and 402, while when it is turned ON, the operation mode thereof is switched to an operation mode in which an ID code is transmitted at step 403, and then switched again to a receiving mode carried out along steps 404 and 405.

The operation of the tag of the embodiment shown in FIG. 5 will be explained with reference to the timing chart of FIG. 7 hereunder.

The sections g to 1 illustrate waveform signals at corresponding portions in FIG. 6.

As shown in FIG. 7, the interrogator 100 is continuously transmitting an unmodulated microwave therefrom until a response from the tag 300 is received.

When the tag 300 entered into a discriminating area of the interrogator 100 at a time T_1, the CPU starts to operate at time T_2.

During the time T_3 to T_4, the tag modulates the microwave thus received with an ID code thereof and transmits the modulated microwave to the interrogator 100.

The interrogator 100, receives which the microwave modulated by the ID code from the tag 300, modulates the microwave with an amplitude modulation in response to writing data starting from the time T_5 and transmits the thus AM modulated microwave to the tag again.

The tag 300 receives and detects the AM modulated microwave to rewrite the corresponding data in the RAM 350.

Thereafter, the tag 300 moves out of the identifying area of the interrogator 100 at the time T_6, and the CPU is placed into a waiting mode after a predetermined time for keeping the peak value of the peak detector device 250 has passed.

As explained above, in this embodiment, a data writable tag can be obtained utilizing a microwave circuit having only one antenna and one detection device therein.

According to the present invention, one antenna can be commonly used for an antenna to receive an query radio wave and for to transmit a reflected radio wave modulated in accordance with a coded signal train.

Further, in the present invention, remarkable effects in which the size of the transponder can be significantly minimized can be obtained.

While the invention has been described in terms of certain preferred embodiments, the skilled worker practiced in the art will recognize that there are various changes, modifications, omissions and substitutions that may be made without departing from the spirit thereof.

We claim:

1. A transponder used in a mobile body identification system in which an interrogator generates a query radio wave to a mobile body and receives a radio wave including mobile body information returned from a transponder provided on said mobile body, said transponder comprising:

an antenna for receiving a query radio wave transmitted from said interrogator to activate a code signal generating means and to modulate a signal, and for transmitting a modulated radio wave to said interrogator;

a detection device for detecting said query radio wave received by said antenna and for generating a detection signal;

coded signal generating means for generating a coded signal train output previously stored in response to said detection signal, and

bias controlling means for varying an amount of bias of said detection device in accordance with said coded signal train output and for varying a reflection coefficient of said detection device in accordance with said coded signal train output so that said coded signal train output is returned to said interrogator as a responding radio wave generated by modulating said reflected wave of said query radio wave;

an electric power source controlling means for supplying the electric power to said coded signal generating means when a detection output having a level exceeding a predetermined set level is detected; and

a circuit for eliminating a modulated component modulated by said bias controlling means and which is superimposed on said detection output generated from said detection device to preclude transmitting the modulated wave, such as a second harmonic wave.

2. A transponder for a vehicle identification device according to claim 1, wherein said coded signal train is

previously prepared in accordance with an inherent coded signal of a respective transponder.

3. A transponder for a vehicle identification device according to claim 1, wherein said eliminating circuit eliminates an adverse effect caused by said modulated component by detecting said detection output from said detection device, interposed with said modulated component modulated by said bias controlling means, utilizing an enveloped line detecting method.

4. A transponder for a vehicle identification device according to claim 1, wherein said detection device is a Schottky barrier diode.

5. A transponder for a vehicle identification device according to claim 1, wherein said radio wave is a microwave.

6. A transponder provided on a vehicle and used in a vehicle identification device in which information of said vehicle is read by an interrogator utilizing a microwave in a non-contacting transponder, said transponder comprising:

an antenna for receiving a query microwave transmitted from said interrogator,

a detection device including a detection device for detecting said query microwave received by said antenna and a bias terminal to give a bias voltage to said detection device,

a coded signal generating means for generating a coded signal train previously determined with respect to said information as a modulating signal in response to a detection output generated from said detection device and for applying said modulating signal to said bias terminal to vary the amount of said bias of said detection device so as to vary a reflection coefficient of said detection device in accordance with said coded signal train and to modulate a reflected wave of said query microwave with amplitude modulation (AM) in accordance with said coded signal train to return it back to said interrogator through said antenna;

wherein said transponder is further provided with an electric power source controlling circuit for supplying electric power to said coded signal generating means in response to a detection output generated from said detection device; and

wherein said transponder is further provided with a circuit for eliminating a modulated component caused by said modulated signal output from said coded signal generating means and superimposed on a detection output generated from said detection device to preclude transmitting the modulated wave, such as a second harmonic wave, and

wherein said electric power source controlling circuit supplies electric power to said coded signal generating means in response to a detection output with a modulated component thereof being eliminated by said eliminating circuit.

7. A transponder for, a vehicle identification device according to claim 6, wherein said transponder is further provided with an electric power source controlling circuit for supplying electric power to said coded signal generating means in response to a detection output generated from said detection device.

8. A transponder for vehicle identification device according to claim 7, wherein said transponder is further provided with a circuit for eliminating a modulated component caused by said modulated signal output from said coded signal generating means and superimposed on a detection output generated from said detection device and wherein said electric power source controlling circuit supplies electric power to said coded signal generating means in response to a detection output with a modulated component thereof being eliminated by said eliminating circuit.

9. A transponder for a vehicle identification device according to claim 6, wherein said eliminating circuit detects said detection output generated from said detection device to which modulated components caused by said modulated signal output from said coded signal generating means are superimposed by an envelope detection method.

10. A transponder for a vehicle identification device in which information is transmitted between an interrogator and transponders provided on vehicles utilizing microwaves, each of said transponder comprising:

a detector comprising an antenna for receiving a query microwave generated from said interrogator, a detection device, and a bias terminal for biasing said detection device, said detector functioning such that said query microwave received by said antenna is modulated with amplitude modulation (AM) in two conditions such as a reflecting and absorbing condition, a reflection wave of said modulated query microwave is returned back to said interrogator from said antenna as a responding microwave, then said microwave thus received is detected,

a coded signal generating means for outputting predetermined coded signal trains as a modulating signal in response to said vehicle information and varying an amount of bias of said detection device in response to said coded signal train by applying said modulating signal to said bias terminal, whereby a reflection coefficient of said detection device is varied in response to said coded signal train,

a circuit for eliminating modulated components by said modulating signal generated from said coded signal generating means and superimposed on a detection output detected by said detector, from said detection output, to preclude transmitting the modulated wave, such as a second harmonic wave, and

an electric power source controlling means for supplying electric power to said coded signal generating means in response to said detection output, said modulated components thereof being eliminated therefrom by said eliminating circuit to give operating time for said coded signal generating means.

* * * * *

United States Patent [19]

Baldwin et al.

[11] **4,075,632**

[45] **Feb. 21, 1978**

[54] **INTERROGATION, AND DETECTION SYSTEM**

[75] Inventors: **Howard A. Baldwin; Steven W. Depp; Alfred R. Koelle; Robert W. Freyman,** all of Los Alamos, N. Mex.

[73] Assignee: **The United States of America as represented by the United States Department of Energy, Washington, D.C.**

[21] Appl. No.: **689,708**

[22] Filed: **May 24, 1976**

Related U.S. Application Data

[63] Continuation of Ser. No. 501,020, Aug. 27, 1974, abandoned.

[51] **Int. Cl.^{2}** **G01S 9/56; H04B 1/59**

[52] **U.S. Cl.** .... **343/6.8 R;** 325/113

[58] **Field of Search** .... 343/6.8 R, 6.8 LC; 325/8, 113, 140

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3,460,139	8/1969	Rittenbach	343/6.5 R X
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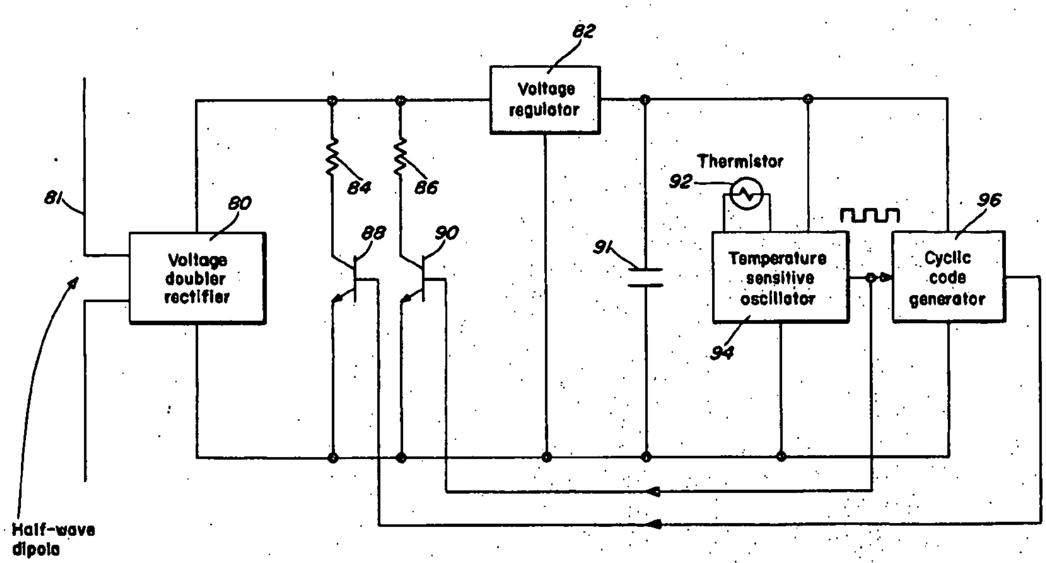
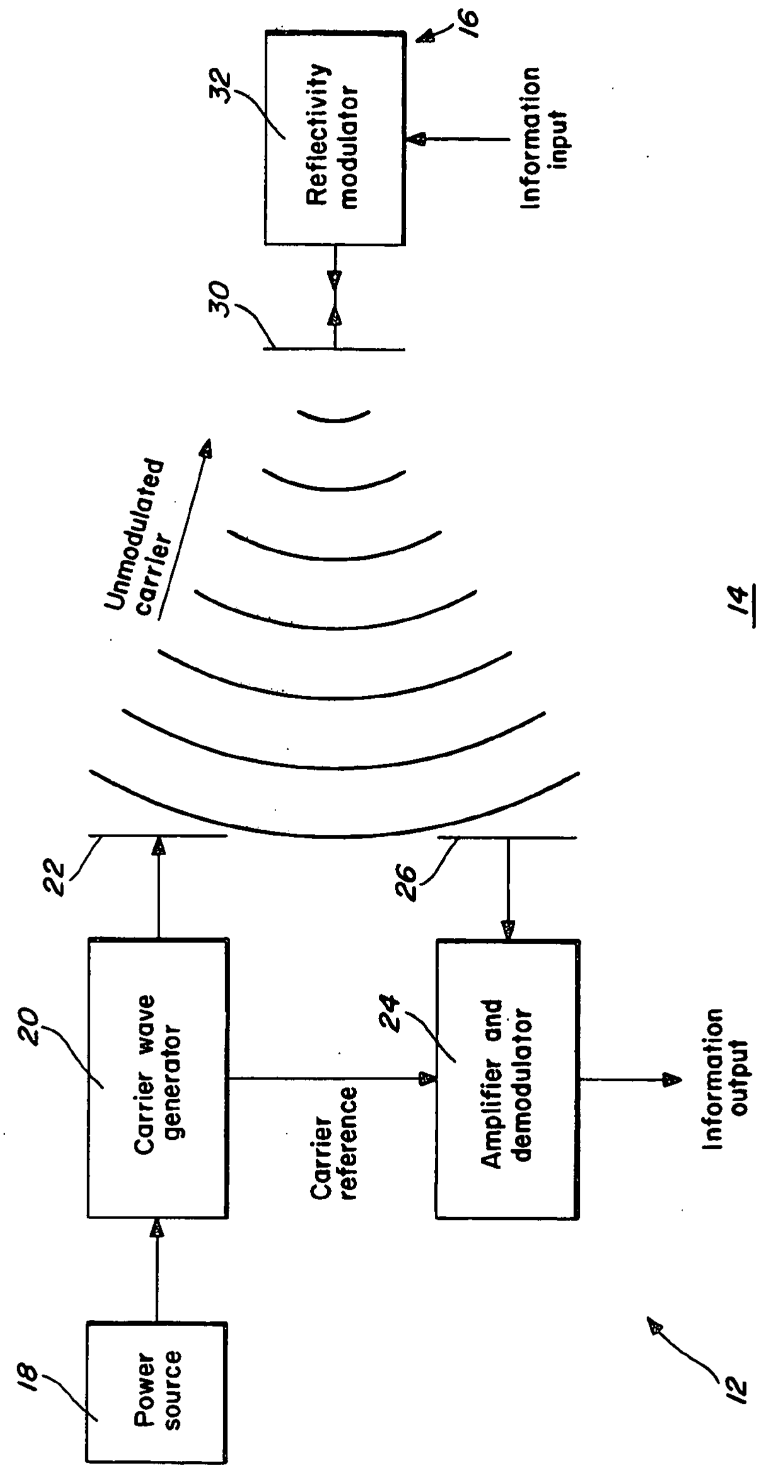
Primary Examiner—Malcolm F. Hubler
Attorney, Agent, or Firm—Dean E. Carlson; Jerome B. Rockwood

[57] **ABSTRACT**

The specification relates to a telemetering apparatus comprising a generator which generates at least a single frequency rf signal, a transponder for receiving that signal and for amplitude modulating it in accordance with information selected for transmission, an antenna on the transponder for reflecting the amplitude modulated signal, and a receiver which is preferably located at the generator. The receiver processes the signal to determine the information carried thereby.

10 Claims, 8 Drawing Figures





16
32
Reflectivity modulator
Information input
30
Unmodulated carrier
14
22
26
20
Carrier wave generator
Carrier reference
24
Amplifier and demodulator
Information output
18
Power source
12

Fig. 1

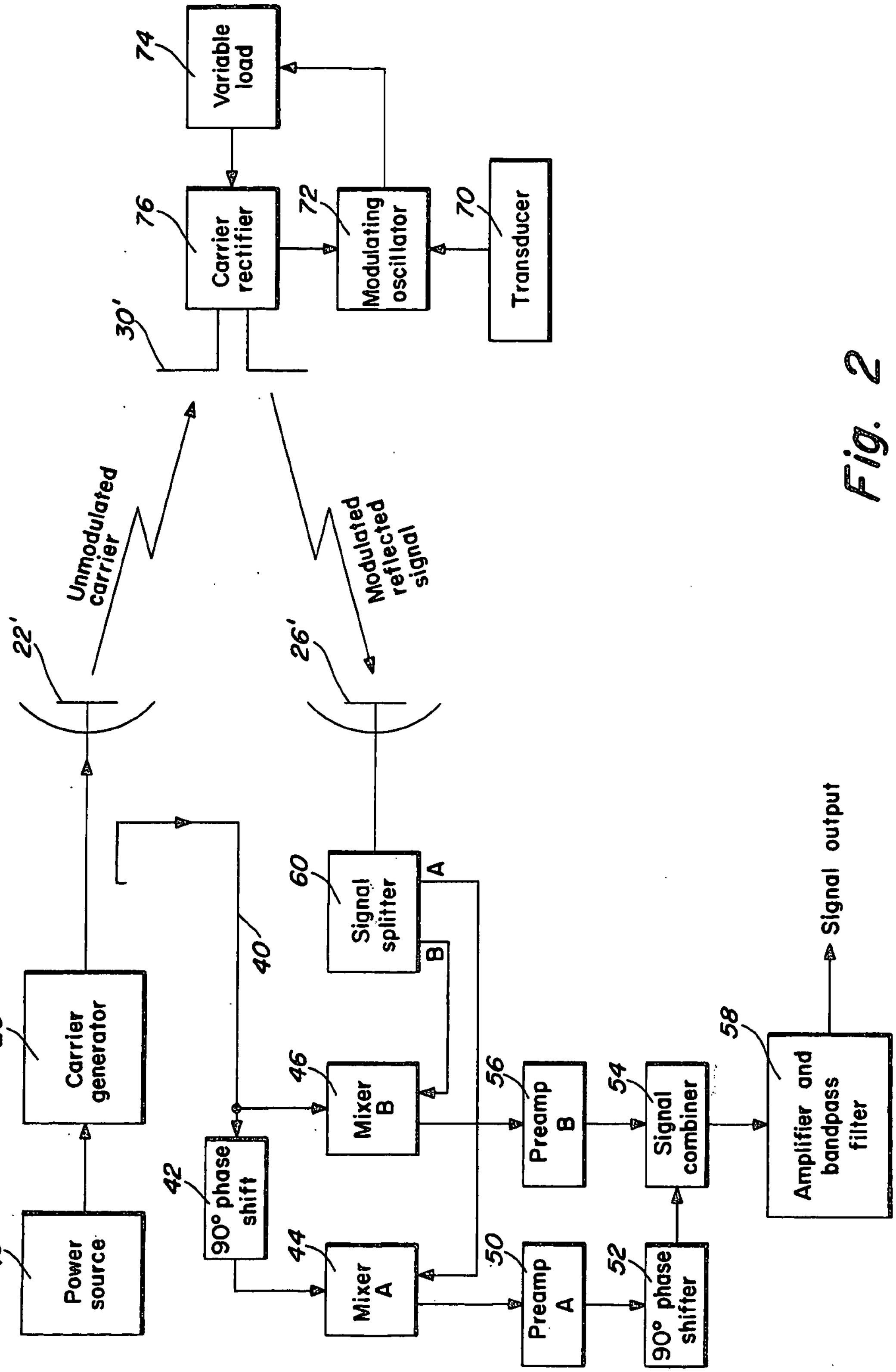

Variable load
74
Carrier rectifier
76
Modulating oscillator
72
Transducer
70
30'
Unmodulated carrier
Modulated reflected signal
22'
26'
Power source
18'
Carrier generator
20'
40
Signal splitter
60
A
B
90° phase shift
42
Mixer A
44
Mixer B
46
Preamp A
50
Preamp B
56
90° phase shifter
52
Signal combiner
54
Amplifier and bandpass filter
58
Signal output

Fig. 2

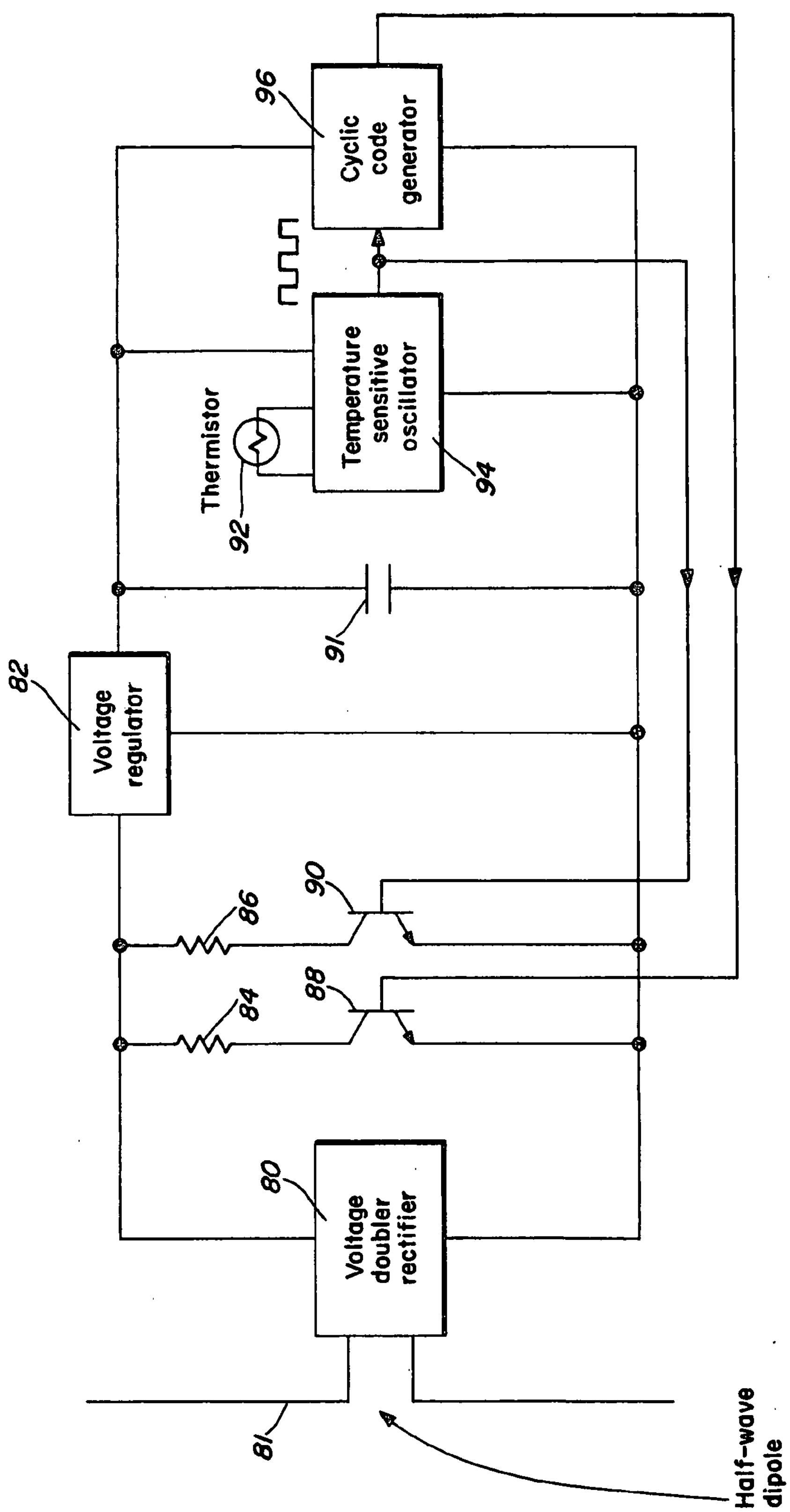
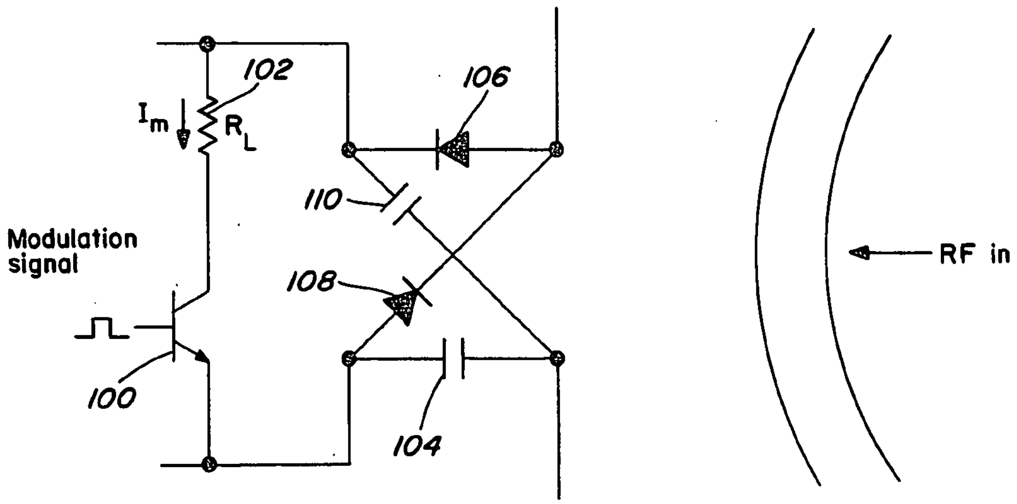
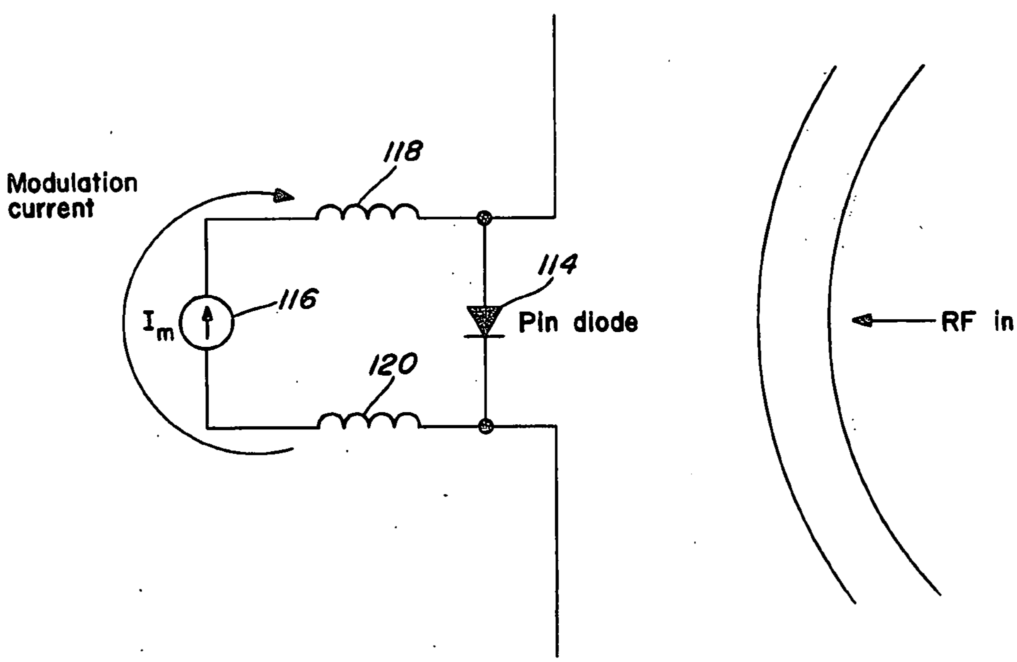

96
Cyclic code generator
Temperature sensitive oscillator
94
Thermistor
92
91
82
Voltage regulator
86
90
84
88
80
Voltage doubler rectifier
81
Half-wave dipole

Fig. 3



Modulation by loading rectifier

Fig. 4



Modulation by pin diode

Fig. 5

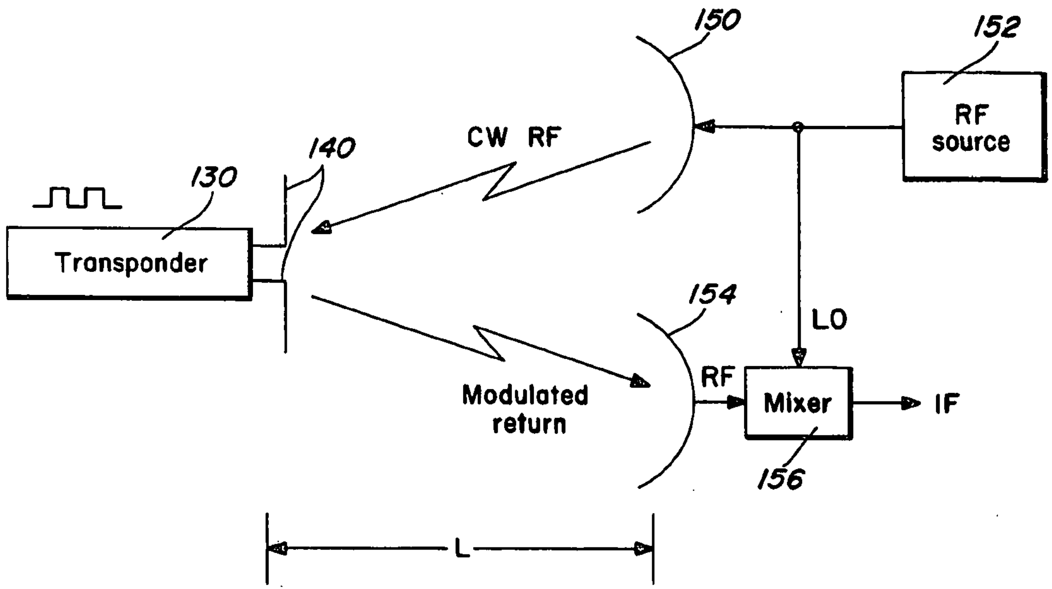

150
152
RF source
CW RF
140
130
Transponder
154
LO
RF
Mixer
IF
Modulated return
156
L

Fig. 6

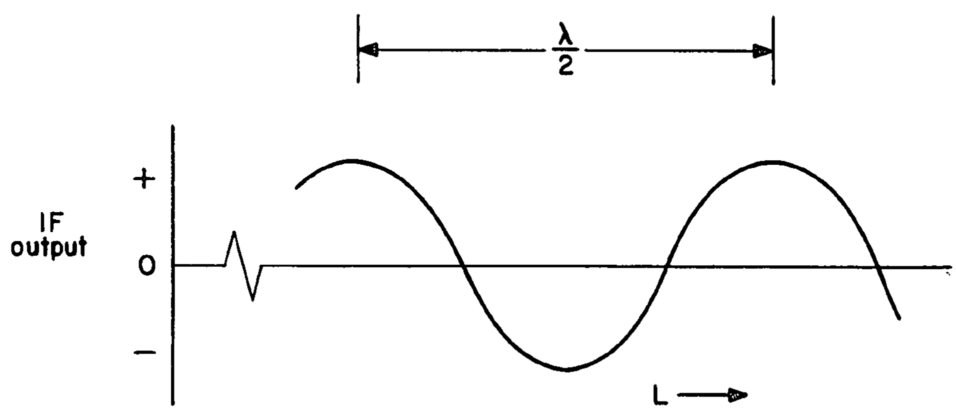

λ/2
+
IF output
0
−
L

Fig. 7

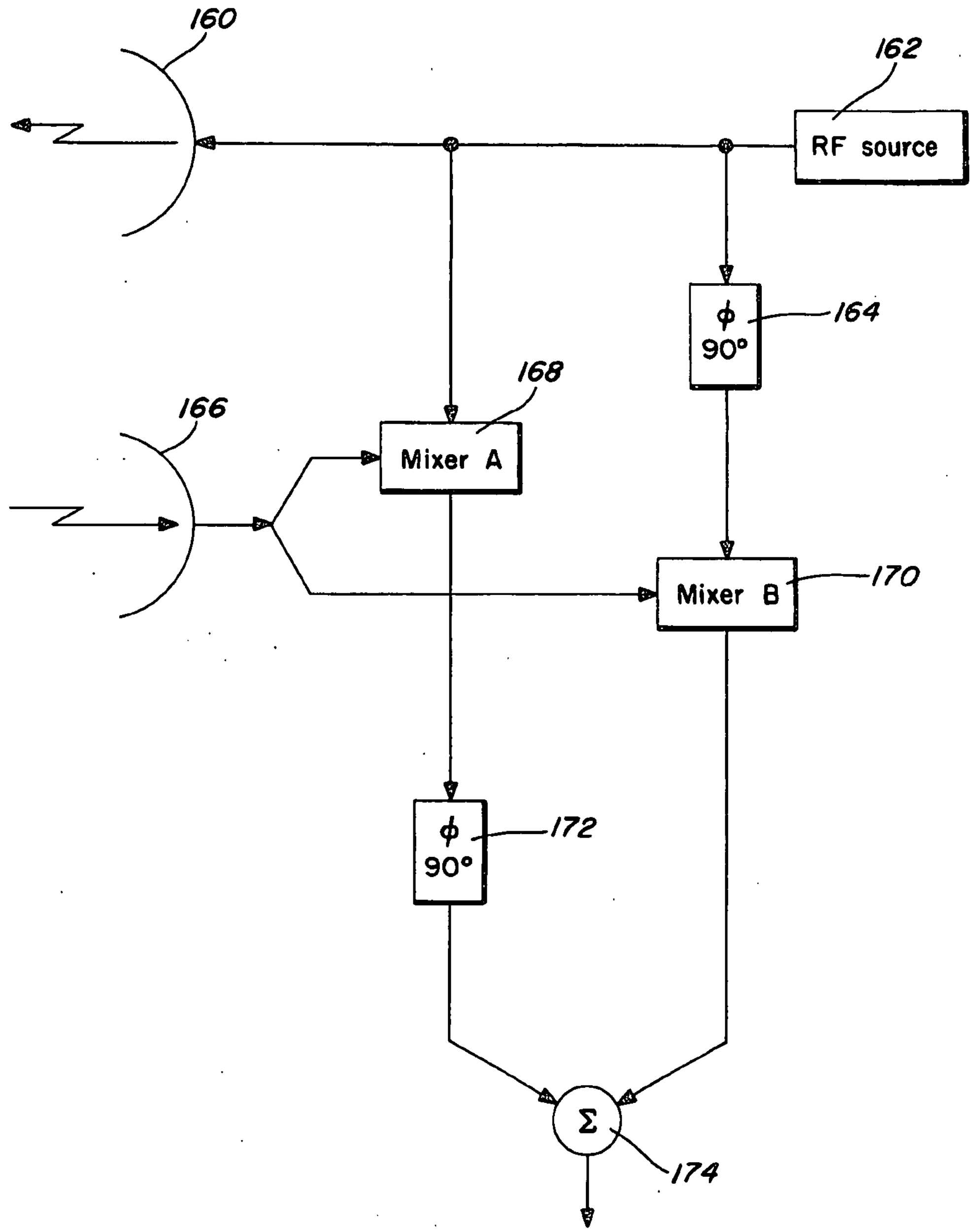

160
162
RF source
ϕ
90°
164
168
166
Mixer A
Mixer B
170
ϕ
90°
172
Σ
174

Fig. 8

INTERROGATION, AND DETECTION SYSTEM

The invention described herein was made in the course of, or under, a contract with the U.S. ATOMIC ENERGY COMMISSION.

This is a continuation of application Ser. No. 501,020, filed Aug. 27, 1974, now abandoned.

FIELD OF THE INVENTION

The invention relates to telemetering and in particular to a system for amplitude modulating a first signal in accordance with selected information and for reflecting the amplitude modulating signal to a receiver for processing the modulated signal to determine the information carried thereby.

BACKGROUND OF THE INVENTION

Although the system of the invention has many applications, including, but not limited to motor vehicle identification, railroad car identification, inventory control, security systems, locating and tracking vehicles, monitoring from inaccessible locations, downed aircraft location, battlefield monitoring, and environmental monitoring, the preferred embodiment was developed for biomedical monitoring and in particular for identifying the health of selected animals. It will be appreciated by those skilled in the art that many methods of identifying animals are practiced by those in the livestock industry. However, none of these prior art methods are universally effective or utilized because of various shortcomings in each of such systems. Exemplary of those shortcomings are loss of the identification carried by the animal, poor visibility of the animal, and human errors in reading or transcribing.

There has been an existing need in the agricultural industry to identify particular animals and to determine, for example, the temperature of the animal as an indication of its health. It would be preferable that an animal monitoring system be amenable to automation and compatible with computer data processing methods so that much information on many animals can be more easily and errorlessly processed than has been possible with prior art systems. The system of the invention can be used to facilitate detailed records on such things as pedigree, food intake, fertility, preventative medical care, resistance to a disease, response to treatment, costs, sales, show performance and livestock movement. For food animals the invention can provide information from which one can compute conversion efficiency and relate management practices to carcass properties. The system of the invention has use in herd improvement for processing and determining relevant information from more factors than it is presently economical to consider.

In addition, the remote monitoring afforded by practicing the invention eliminates excess animal handling by humans and the attendant risk to personnel and animal. The system also eliminates the stress-induced temperature increase frequently associated with handling animals.

SUMMARY OF THE INVENTION

In accordance with the invention, there is provided a telemetering apparatus and method comprising a radio frequency or other frequency signal generator, a transmitter for transmitting a time variant signal comprising at least a selected single frequency, a transponder spaced from the transmitter for receiving and for amplitude modulating the signal in accordance with selected information, and a reflecting antenna which returns the amplitude modulated signal to a receiver preferably integral with the generator and transmitter. The receiver processes the modulated return signal to determine the selected information carried thereby. In a preferred embodiment of the invention, the transponder is passive and in an alternative embodiment is active. Both analog and digital information can be transmitted using the system of the invention.

The preferred embodiment of this telemetry system includes means for avoiding the dependence of the phase of the received signal, relative to that of the carrier, upon the physical distance between the interrogator antennas and the transponder antenna. If no such means were used, then the signals would be in quadrature phase relationship every quarter wavelength in spacing between the antennas and there would be zero output from the mixer at the modulating frequency.

One object of the invention is to provide an apparatus and method for animal monitoring.

Another object of the invention is to provide new telemetry capability.

One advantage of the instant invention is that the preferred embodiment thereof utilizes a transponder which eliminates the need for a separate energy source at the transponder.

Another advantage of the instant invention is that in accordance therewith, multiple digit information can be transmitted.

Another advantage of the instant invention is that there is no interference between the transmitted and received signal even though the transmission is continuous.

Still other objects and advantages of the present invention will be apparent to those skilled in the art from the following description, with reference to the appended drawings, wherein like numbers denote like parts and wherein:

FIG. 1 illustrates a block diagram of the preferred embodiment of the invention;

FIG. 2 shows a more detailed block diagram indicating the components of the blocks of FIG. 1;

FIG. 3 shows a detailed schematic of a passive transponder in accordance with the invention;

FIG. 4 shows a loading rectifier modulator for the transponder in FIG. 3;

FIG. 5 shows a PIN diode modulator for the transponder of FIG. 3;

FIG. 6 illustrates a telemetry system utilizing only one mixer;

FIG. 7 shows the interferometer effect with a single mixer; such as in the system of FIG. 6; and

FIG. 8 shows apparatus utilized in accordance with the invention for removing the interferometer effect of the FIG. 6 apparatus.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION

Reference is now made to FIG. 1 which is a block diagram of the preferred embodiment of the invention. The system comprises an interrogator **12**, a transmission medium **14** and a transponder **16**. The signal generating and transmitting portion of the interrogator comprises a power source **18**, a carrier wave generator **20** and a sending transducer or antenna **22**. In addition, the interrogator also comprises an amplifier and demodulator **24**

operably connected to a signal receiving transducer or antenna 26.

The transmission medium preferably comprises air, but a medium such as water or a solid could be utilized in combination with a signal appropriate for traveling therethrough.

The transponder 16 comprises a signal receiving and reflecting antenna 30 and a reflectivity modulator 32 for modulating the signal received by antenna 30 as well as for reflecting the modulated signal from antenna 30. Reflectivity modulator 32 can be disposed, for example, on the animal to be monitored. In the case of a steer which it is desired to monitor for temperature changes, it would be connected to an appropriate thermistor embedded in the animal. However, it will be appreciated by those skilled in the art that what particular information passes through the system of the invention is not part of the invention and the invention is not restricted to the use of the system disclosed herein in animal monitoring. Clearly, the invention may be used by those skilled in the art in many other monitoring environments and applications.

As can be seen from FIG. 1 the power source 18 powers the carrier wave generator 20 to send a generated signal from transducer or antenna 22. The signal from antenna 22 passes through transmission medium 14 and is received by a reflector 30 at the transponder 16. The reflectivity modulator 32 modulates such a signal in accordance with information desired and reflects the amplitude modulated signal from reflector 30 back on to the reflected signal receiving antenna 26. The signal impinging on antenna 26 is picked up by the amplifier and demodulator 24 which processes the signal and determines the information carried thereby.

As will be appreciated by those skilled in the art, power source 18 and carrier wave generator 20 are readily available pieces of equipment. Too, radio frequency transmitting and receiving antennas such as antennas 22, 26 and 30, are well known to those skilled in the art. Thus, no further discussion need be made of these components.

While the telemetry system shown in the block diagram of FIG. 1 is a preferred embodiment of this invention, typical of what might be used at radio frequencies, there are many variations that will be obvious to those familiar with radio frequency communication and telemetry techniques.

The carrier generated at the interrogator need not be continuous wave or constant in amplitude and/or frequency. It may be appropriate in some applications to generate the carrier intermittently. This might be done for various reasons such as to conserve power, to minimize interference with other users of the spectrum, or for other reasons. Similarly, there may be situations where it might be useful to modulate the carrier in a particular area of a plurality of various ways. For example, command signals or information could be sent to the transponder unit from the interrogator by appropriately modulating the carrier sent from the interrogator. Such modulation of the carrier could be done in such a way as to not interfer with the modulation superimposed on the reflected carrier signal at the transponder. The information added to the carrier at the transponder could be made distinguishable and separable from that sent to the transponder by, for example, using sufficiently separated modulation frequencies or by using a different form of modulation, such as for example pulse modulation generated at the transponder superimposed on a variable frequency amplitude modulation sent from the interrogator. There are many other possible combinations which will be readily recognizable to those familiar with the state of the art in communications, telemetry, and radio control.

FIG. 2 shows a more detailed block diagram of the preferred embodiment of the invention. As seen therein, power source 18' carrier wave generator 20', and antennas 22' 26' and 30' correspond to their unprimed numbers in FIG. 1. The amplifier and demodulator of FIG. 1 is broken down into its components in FIG. 2. The amplifier and demodulator comprises an attenuated carrier conduit 40, which passes a portion of the wave generated by generator 20' through a 90° phase shifter 42 to a mixer 44. Part of the generated wave goes directly to a mixer 46. From mixer 44, the phase shifted portion of the generated signal passes through a preamplifier 50 and 90° phase shifter 52 at the modulation frequency into a signal combiner 54. The signal from mixer 46 passes through a preamplifier 56 into signal combiner 54. The combined signals pass from signal combiner 54 into an amplifier and bandpass filter 58 to produce an output signal. The reflected signal received by antenna 26' passes into a signal splitter 60 which outputs into both mixer 44 and 46 where portions of the reflected signal are mixed with the portions of the generated signals.

While 90° phase shift devices are shown, any other combination of phase shifting means which will result in a net 90° phase difference between the local oscillator inputs to the mixers or a 90° phase difference between the receiver inputs to the mixers, or a combination of the two, will be suitable.

The transponder comprises a transducer 70, a modulation oscillator 72, a variable load 74 and a carrier rectifier 76 as well as antenna 30'.

In operation, power source 18' generates energy to power carrier wave generator 20'. Generator 20' produces a time variable signal, preferrably a single frequency radio frequency signal. The rf signal is transmitted by carrier sending antenna 22' through the medium onto transponder antenna 30'. The received signal is rectified and modulated by oscillator 72 driven with transducer 70. The transponder can be a passive transponder, powered by energy from the signal receivedd by antenna 30'. It may also be active, powered by energy from its own separate source. In any case, transducer 70 causes modulation oscillator 72 to oscillate in accordance with the transduced parameter. The modulated oscillator signal passes through variable load 74 which amplitude modulates the signal. This modulated signal is reflected by carrier rectifier 76 through antenna 30'. Receiving antenna 26' receives the reflected modulated signal and passes it to signal splitter 60. Both the attenuated carrier signal from carrier wave generator 20' and the reflected modulated signal enter mixers 44 and 46. The mixers send their output through preamplifiers 50 and 56, and in the case of preamplifier 50, through a 90° phase shifter so that the signals entering combiner 54 are 90° or 270° out of phase and never 180° out of phase. The amplitude modulation in the reflected signal produced by the transponder shows up at the output of the signal combiner 54. It will be appreciated by those skilled in the art, that following or preceding the preamplifiers, any combination of phase-shifting devices which will result in a net quadrature phase relationship at the modulation frequency or band of frequencies between the two mixer output channels will

be suitable. The output signal passes through an amplifier and a bandpass filter 58, to amplify the signal to an appropriate level and to eliminate noise. The resulting output represents the information transmitted from the transponder.

The output signal may be further processed as is appropriate for the particular application. For example, if the modulating frequency itself is the information, the output signal can be sent to a frequency counter to measure the frequency. If the information consists of amplitude, pulse, digital, phase, frequency or other modulation superimposed on the modulation frequency, appropriate means can be used to extract the information of interest.

It will be appreciated since no carrier signal is generated by the transponder there need be no large power source at that location to provide sufficient power to generate a carrier which would carry the information from the information sending terminal to the information receiving terminal, nor a means for determining the frequency of such a locally generated carrier.

A major advantage of the system of the invention is that the carrier frequency is available in pure unmodulated form in any location physically close to the information receiver. This provides for the use of coherent detection at the receiver. For example, in an rf system, a portion of the carrier signal from the carrier generator can be used as a local oscillator input to the receiver mixer as shown in FIG. 2. Alternatively, the local oscillator signal could be created by translating the carrier frequency in a small fixed or variable amount. The advantage of coherent detection is that system bandwidth can be reduced to that necessary for passing the information signal only, with a minimization of noise.

Naturally, reduced bandwidth enables better noise rejection. The use of coherent detection also eliminates the necessity for close control over carrier frequency, providing for the use of simpler and lower cost carrier generation devices than would otherwise be required.

It is possible to get response from one transponder to two interrogators or more, simultaneously and without interference. All that is required is sufficient difference in the carrier frequencies to put the frequency difference outside the modulation signal passband.

While only a single transponder antenna is shown in FIG. 2, two or more antennas may be suitably interconnected into an array so as to receive and reflect a larger amount of carrier power. Such an array can also be used to produce directivity for the transponder antenna. Alternatively, any of the known methods for making a directive antenna can be used at the transponder to augment the directivity and power gain of the transponder antenna.

Although FIG. 2 shows only a single transponder, two or more transponders may be used simultaneously. Information from a plurality of transponders can be received in one or more of a number of different ways. For example, the carrier from the interrogator can be beamed selectively to one or more of the transponders. In addition, different modulation frequencies can be used at the different transponders and the information separated at the receiver with appropriate bandpass filters. One can also arrange to have the transponders send information at different prearranged times. One could also superimpose a unique, prearranged identification code on the transponder return signal so that the transponder originating a signal could be recognized. Alternatively, a unique interrogation command or control signal for each transponder can be impressed as modulation on the carrier sent from the interrogator to commad response from a particular transponder.

The modulating signal fed to the variable load may be in the form of audio signals, pulses, digital signals, video signals and other signals that will be familiar to anyone conversant to the state of the art. The frequency of the modulating oscillator may be determined by the state of closure of a switch or an array of switches. In addition, a combination of modulations may be used, such as digital information superimposed on a modulation frequency determined by a physical parameter.

While the description of the system shown in FIG. 2 specifically shows amplitude modulation of the carrier signal reflected from the transponder unit, there are other ways to vary the reflectance characteristics at the transponder to produce a reflected carrier with superimposed information which can be extracted at the interrogator. For example, it is possible to vary the phase of the returned signal instead of its amplitude, or use a combination of the two methods. Phase modulation could be produced, for example, by varying a reactance placed across the transponder antenna. Alternatively, phase differences in the return signal can be generated by using two or more antennas appropriately different in distance from the interrogator antenna and amplitude modulating the reflectivity of each. If such phase modulation is used, then the means used at the interrogator receiver to make the receiver insensitive to the phase of the returned signal would not be used.

FIG. 3 shows in block diagram form, the circuitry of a passive (rf beam-powered) transponder to convey both temperature and digital information. The temperature is sensed in analog form by a thermistor 92 connected to a temperature sensitive oscillator 94, which is made suitably temperature sensitive in its oscillation frequency by having the thermistor connected into one of the frequency determining resistances. Alternatively two or more thermistors could be used.

An rf signal received by a half-wave dipole antenna 81 is passed to a voltage doubler rectifier 80. A voltage doubler type of rectifier is used to give twice the dc output voltage as would be available from a simple half-wave rectifier. Any other type of rectifier can be used, but a voltage doubler is the preferable one.

In this circuit, the dc voltage from the rectifier 80 is used to power the transponder circuitry. Of course, the transponder circuitry could be powered from a different power source such as in the aforementioned active transponder embodiment. When the rectified rf is used to power the circuitry, a voltage regulator 82 is interposed between the rectifier output and the circuitry to be powered. This ensures that a suitably regulated voltage is available for the circuitry. An energy storage capacitor 91 is used following the voltage regulator. The purpose of this is to store operating energy for the circuitry to provide operation during the low rectifier output voltage periods that will be generated in the amplitude modulation process.

Transistor 90 is used as a swich, driven by the output of the temperature sensitive oscillator 94, and alternately, in effect, placing resistor 86 across the output terminals of the rectifier. Resistor 86 is selected to be of such resistance that it will partially modulate the reflectance of the antenna and, with only transistor 90 and resistor 86 in operation, the antenna reflectance will be modulated in accordance with the frequency of the temperature sensitive oscillator 94. Because the modula-

tion frequency is dependent upon the temperature sensed by the thermistor **92**, the reflected rf is therefore amplitude modulated at a frequency dependent upon the temperature.

In the use of the transponder to send a fixed digital code for identification means, the depth of modulation produced by the temperature sensitive oscillator is varied in accordance with a lower frequency digital signal which comprises a suitable unique code corresponding to the identity of a particular transponder. In the preferred embodiment, the rate of this identification signal is made an integral fraction of the rate of the oscillator, but this need not be so.

In the circuit shown, the depth of modulation is varied in accordance with the digital code by means of transistors **88** and **90**. Transistor **90** is driven by the oscillator. Transistor **88** is driven by the cyclic code generator, which produces the identification code. In the preferred circuit the code is generated repeatedly as long as the circuit is powered, but this is not necessary. Transistors **88** and **90** comprise a logical AND circuit and this is one means for performing that logical function. When both transistors **88** and **90** are turned on, a resistor **84** is effectively disposed across the output terminals of rectifier **80**.

It will be apparent that when both resistors **84** and **86** are placed across the rectifier terminals, rectifier **80** is more heavily loaded than when only resistor **86** is placed across the rectifier. Therefore, more energy is extracted from the rectifier.

Modulation of the return signal by loading the transponder antenna is shown in FIGS. **4** and **5**. FIG. **4** shows modulation by a loading rectifier whereas FIG. **5** illustrates modulation by PIN diode. The rf current flowing in the antenna is a function of the dc load on the rectifier output. The heavier the dc load, the greater the rf current flowing from the antenna into the rectifier input. The rf reflected or scattered from the antenna is proportional to the rf current flowing in the antenna. Since this rf current is a function of the dc load on the rectifier, the reflected rf from the antenna is also a function of the dc load on the rectifier.

In accordance with the invention, rf reflected from the transponder antenna can be modulated by any means that alters the rf current flowing in the antenna. Any means that can be used to alter the resistance, or reactance across the antenna terminals in accordance with a desired modulation pattern can be used. FIG. **4** shows a voltage doubler rectifier, but any other rectifier arrangement could be used.

The rf current flowing into the rectifier from the antenna is a function of the dc current extracted from the rectifier. The higher the dc load on the output, the higher the rf current flowing from the antenna. One means of varying the load current from the rectifier output is to vary the value of a resistance placed across the rectifier output. In FIG. **4**, resistor **102** is switched in and out of the circuit by a transistor **100**.

A rectifier comprising diodes **106** and **108** and capacitors **104** and **110** is a preferred means of modulation for a passive transponder since the dc output from the rectifier can be used to supply power to the transponder circuitry.

As shown in FIG. **5**, another means for varying the rf current in the antenna and thereby modulating the rf signal reflected from it, is to use a PIN **114** diode as a variable rf resistance. The rf resistance of PIN diode **114** is controlled by varying a low frequency or dc current **116** passing through the diode. A suitable pair of inductors **116** and **118** or other suitable means that present a high impedance to rf and a low impedance to the modulation current can be used to isolate the modulation circuitry from the antenna.

FIG. **6** shows a system utilizing a single antenna for both transmitting an rf carrier from the rf generator and receiving the reflected signal and passing it to the receiver mixer while blocking the much larger transmitted carrier signal.

A 3-port circulator is used. This is a device commonly used in microwave rf systems for similar isolation applications. The three ports are labeled A, R, and T to indicate respectively antenna, receiver, and transmitter. The circulator device has the property that rf eneregy is passed with little attenuation from one port to the next in the clockwise direction as shown in FIG. **6**. For example, the transmitter signal is passed with little loss from port T to port A and from there to the antenna. Similarly, the signal received at the antenna is passed easily from port A to port R and from there to the receiver mixers. Signal transmission in the other direction, which is not desired, is almost completely blocked by the action of the circulator. Reverse signal transmission is typically a factor of 20 to 30 dB lower than forward signal transmission. This is called the directivity of the circulator.

In the circuit of FIG. **6**, the circulator is used to allow operation from a single antenna. The rf carrier from the rf source is preferentially passed to the antenna and is blocked from passing to the receiver input, where it is not wanted. Similarly, the reflected rf signal picked up at the antenna is preferentially passed to the receiver input and is blocked from passing back to the rf source, where it would be wasted.

Since the circulator only has a finite amount of directivity, however, it is usually the case that the small amount of reverse transmission in the circulator from port T to port R would result in more rf carrier being sent to the receiver input than is desired. One consequence of this could be to destroy the receiver mixers and another could be to cause the mixers to malfunction. A means to overcome this difficulty is to arrange to feed into port A of the circulator some rf signal of the proper amplitude and phase to pass through the circulator from port A to port R to just cancel the reverse transmitted "leakage" from port T. One way of implementing this is to interpose a suitable rf tuning device between port A and the antenna. A double stub tuner is such a suitable device. The tuner has the additional function of matching the antenna impedance for maximum efficiency in both transmitting and receiving the rf signals.

FIG. **6** shows the path of the rf signals in simplified form. The rf carrier is sent from an antenna **150** from an rf source **152**. The carrier passes through a transmission medium to an antenna **140** on a transponder **130**, from which a modulated signal is reflected back to a receiving antenna **154**. A separate receiving antenna is shown for simplicity in description, though in practice suitable means are available for using a single antenna. The received signal is passed to a mixer **156**, where it is mixed with an attenuated unmodulated signal from the rf source fed into the LO or "local oscillator" port.

The output from the mixer **156**, usually designated the IF or "intermediate frequency" output in ordinary receiver practice, is a replica of the signal used to modulate the rf signal at the transponder and therefore con-

tains the information put on the rf signal at the transponder. However, the amplitude and phase of this modulation signal are affected by the relative rf phase of the rf and LO inputs to the mixer. The relative phase of these signals is determined by the distance that the rf signal traverses in going from the transmitting antenna to the transponder and back to the receiving antenna, including also the distances in the connection from the antennas to the mixer. As this distance varies, the relative phase of the rf inputs to the mixer vary. One particular disadvantage of this is that if the rf and LO inputs happen to be quadrature phase, the mixer output will be zero, i.e., the output will pass through a "null." This is particularly disadvantageous when the transponder is in motion relative to the transmitter/receiver antenna unit and vice versa since the receiver signal may drop out, causing some information to become lost.

This undesired effect has been called the "interferometer" effect since the principle causing it is similar to that of an interferometer.

FIG. 7 shows how the amplitude and phase of the mixer output are a function of the distance between the transponder and the transmitter/receiving antenna unit. It will be seen that the relationship is sinusoidal with distance, being cyclic with a half wavelength at the rf carrier frequency used and dropping to zero in amplitude every quarter wavelength.

FIG. 8 shows a system for removing the interferometer effect of FIGS. 6 and 7 and for making signal reception from the transponder independent of the distance between antennas 160 and 166.

A single rf source 162 is utilized. Two rf mixers 168 and 170 are used instead of only the single one common in most receiver systems. A phase shifting 164 ensures that there is a relative 90° difference in the phases between the rf and LO inputs to the two mixers. Alternatively, this phase shift could be introduced in the rf input of one of the mixers, or split up in one of a number of different ways to get the net 90° difference. Thus, if the phase relationships are such that one of the mixer outputs is at a null point, the other output is at a maximum, and vice versa. It will be appreciated that it is impossible for both mixer outputs to be at a null at the same time. Therefore there will always be a mixer output from which the modulation signal can be obtained.

While mixer output signals cannot be zero or null at the same time, their amplitude will vary with the rf phase or antenna spacing and their outputs may be in phase or out of phase at the modulation frequency. This makes it difficult to utilize the mixer outputs directly to recover the modulation signal.

FIG. 9 illustrates a system avoiding this difficulty. A relative 90° phase shift at the modulation frequency is produced between the two mixer outputs by phase shifter 172. The phase shifted signals are linearly combined by summing amplifier 174 to produce a single output at the modulation frequency. Of course, any method that produces a net 90° phase shift between the mixer output signals should function as well as phase shifter 172.

The effect of combining the mixer output signals is to make the combined signal amplitude independent of the rf signal phase and therefore of the antenna spacing. Qualitatively, it is easy to see that if the mixer output signals at the modulation frequency are phase shifted to be in quadrature phase with respect to each other, they cannot cancel each other out to zero in the linear combining operation, and therefore there will always be some combined output signal at the modulation frequency. A more careful analysis will show that the amplitude is actually constant.

The various features and advantages of the invention are thought to be clear from the foregoing description. However, various other features and advantages not specifically enumerated will undoubtedly occur to those versed in the art, as likewise will many variations and modifications of the preferred embodiment illustrated, all of which may be achieved without departing from the spirit and scope of the invention as defined by the following claims.

We claim:

1. In telemetry apparatus, a passive transponder comprising:

an antenna;

rectifier means having a first pair of terminals connected to said antenna and having a second pair of terminals providing direct current;

variable loading means connected to said second pair of terminals; and

information encoding means in circuit with said variable loading means to enable encoded information to vary the direct current drawn from said rectifier by said variable loading means, thereby varying the impedance of said rectifier means at said first pair of terminals, and varying the reflectivity of said antenna.

2. In the transponder set forth in claim 1, said variable loading means including a resistor in circuit with semiconductor switching means responsive to said information encoding means and connected to said rectifier means.

3. In the transponder set forth in claim 2, said information encoding means including a condition sensitive variable frequency oscillator.

4. In the transponder set forth in claim 3, a voltage regulator connected in circuit between said variable loading means and said variable frequency oscillator.

5. In the transponder set forth in claim 1, said rectifier means including current storage capacitor means.

6. In the transponder set forth in claim 5, said rectifier means and said current storage capacitor means forming a voltage doubler rectifier circuit.

7. In the transponder set forth in claim 6, said rectifier means including:

a first diode connected between one of said first pair of terminals and the adjacent one of said second pair of terminals;

a second diode connected to said first diode at one of said first pair of terminals and the opposite one of said second pair of terminals;

a first current storage capacitor connected between the other said first pair of terminals and the adjacent one of said second pair of terminals; and

a second current storage capacitor connected to said first diode at said first pair of terminals and to said first current storage capacitor at said first pair of terminals.

8. In the transponder set forth in claim 3, said information encoding means further including cyclic code generator means connected to said variable frequency oscillator.

9. In the transponder set forth in claim 8, second variable loading means connected to said cyclic code generator.

10. A passive transponder adapted to be implanted beneath the skin of a living animal, comprising:

an antenna;

a voltage doubling rectifier having first and second terminals connected to said antenna, and having third and fourth terminals;

an audio frequency oscillator;

a temperature sensitive resistor connected to said audio oscillator to vary the frequency of said audio oscillator in response to ambient temperature changes;

variable rectifier loading means including a resistor connected to said third terminal, a transistor having a collector connected to said resistor, an emitter connected to said fourth terminal, and a base electrode connected to said audio frequency oscillator.

* * * * *

US005649295A

United States Patent [19]

Shober et al.

[11] Patent Number: 5,649,295

[45] Date of Patent: Jul. 15, 1997

[54] **DUAL MODE MODULATED BACKSCATTER SYSTEM**

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[73] Assignee: **Lucent Technologies Inc.**, Murray Hill, N.J.

[21] Appl. No.: **492,173**

[22] Filed: **Jun. 19, 1995**

[51] **Int. Cl.**[6] **H04B 1/40**; H04B 1/59

[52] **U.S. Cl.** **455/38.2**; 455/73; 455/106; 455/517; 342/51

[58] **Field of Search** 455/38.2, 49.1, 455/54.1, 54.2, 73, 106, 19; 340/572, 573, 825.54; 342/44, 51, 50

[56] **References Cited**

U.S. PATENT DOCUMENTS

2,259,227	8/1941	Pescod	340/825.54
4,075,632	2/1978	Baldwin et al.	343/6.8 R
4,360,810	11/1982	Landt	343/6.8 R
5,252,979	10/1993	Nysen	455/73
5,317,309	5/1994	Vercellotti et al.	340/825.54
5,319,802	6/1994	Camiade et al.	455/54.1

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Attorney, Agent, or Firm—John A. Caccuro

[57] **ABSTRACT**

A radio communication system includes an Interrogator for generating and transmitting a first modulated signal by modulating a first information signal onto a radio carrier signal, the first information signal indicating in which of multiple response modes a receiving Tag should respond. One or more Tags of the system receive the first modulated signal and decode it to obtain the first information signal. A Backscatter Modulator modulates the reflection of the first modulated signal using a second information signal whose content, data rate, or modulation is determined by said first information signal, thereby forming a second modulated signal. The Interrogator receives and demodulates the second modulated signal to obtain the indicated second information signal.

26 Claims, 4 Drawing Sheets

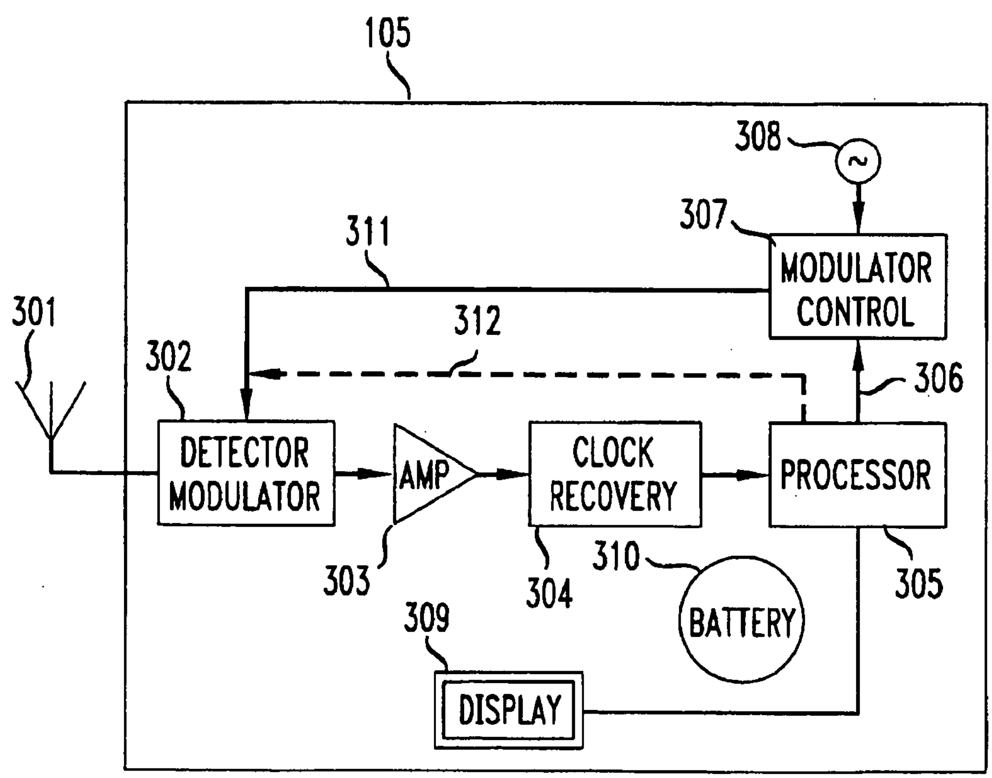


FIG. 1

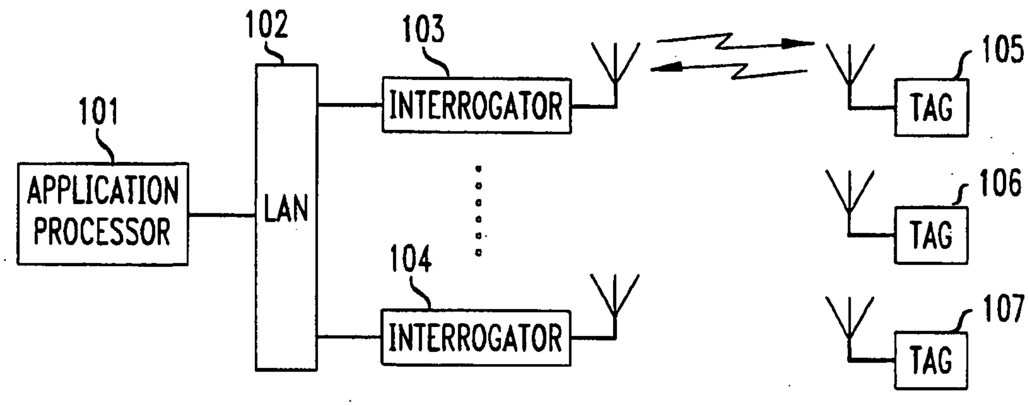

102
103
105
101
APPLICATION PROCESSOR
LAN
INTERROGATOR
TAG
106
TAG
104
INTERROGATOR
107
TAG

FIG. 2

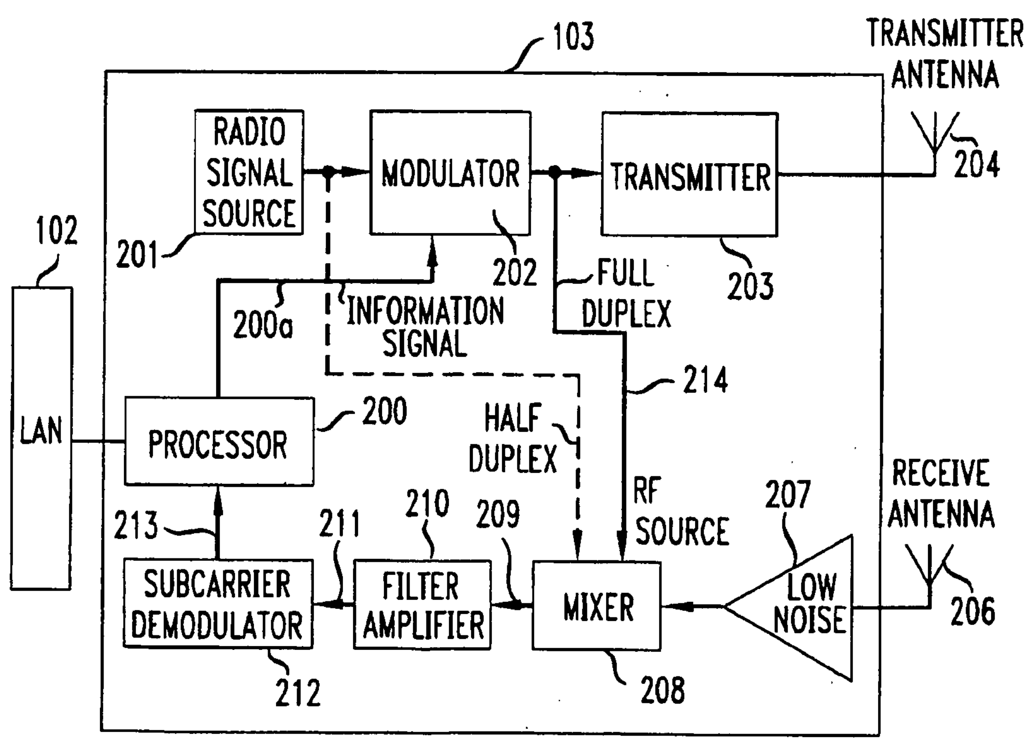

103
TRANSMITTER ANTENNA
RADIO SIGNAL SOURCE
MODULATOR
TRANSMITTER
204
102
201
202
FULL DUPLEX
203
200a
INFORMATION SIGNAL
214
LAN
PROCESSOR
200
HALF DUPLEX
RF SOURCE
207
RECEIVE ANTENNA
213
211
210
209
SUBCARRIER DEMODULATOR
FILTER AMPLIFIER
MIXER
LOW NOISE
206
212
208

FIG. 3

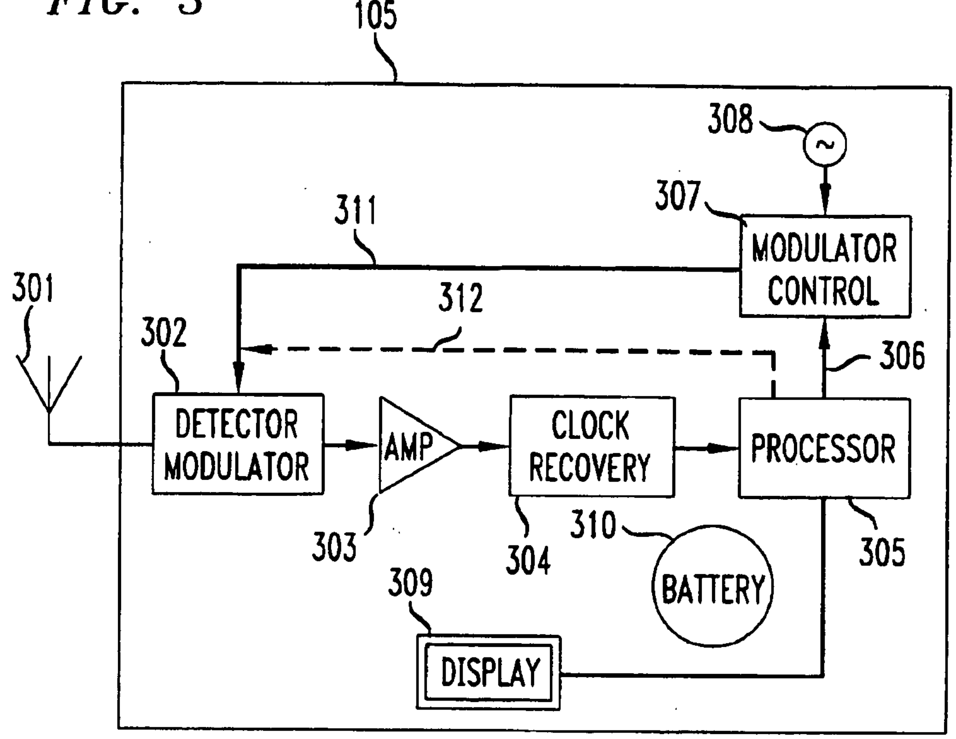

105
308
307
311
MODULATOR
CONTROL
301
312
302
306
DETECTOR
MODULATOR
AMP
CLOCK
RECOVERY
PROCESSOR
303
304
310
305
309
BATTERY
DISPLAY

FIG. 4

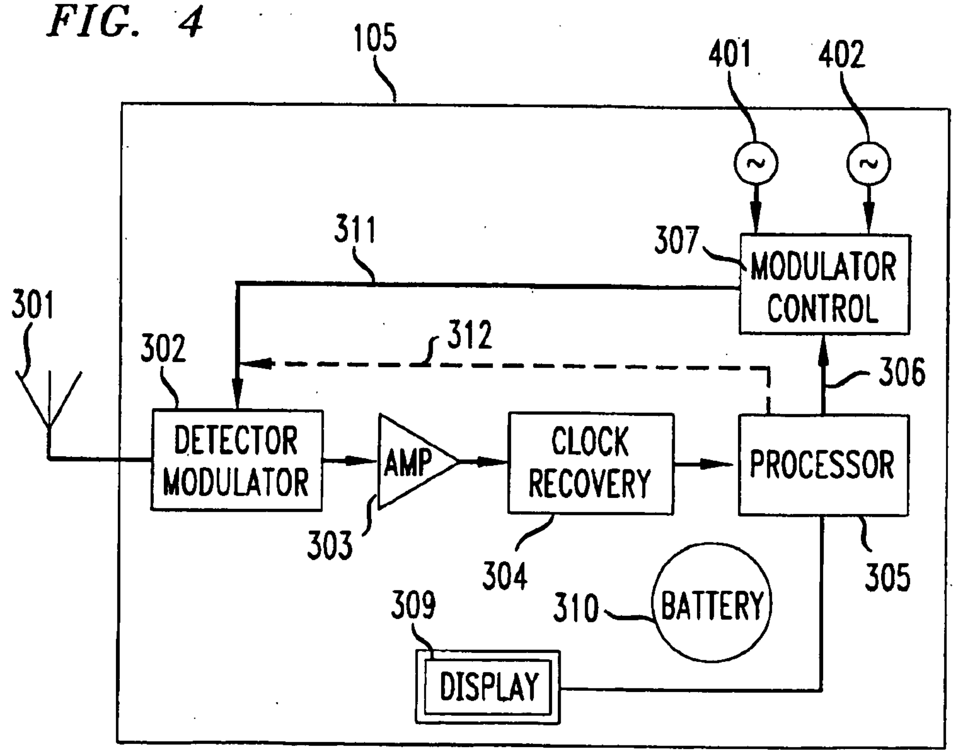

105
401
402
311
307
MODULATOR
CONTROL
301
312
302
306
DETECTOR
MODULATOR
AMP
CLOCK
RECOVERY
PROCESSOR
303
304
305
309
310
BATTERY
DISPLAY

FIG. 5

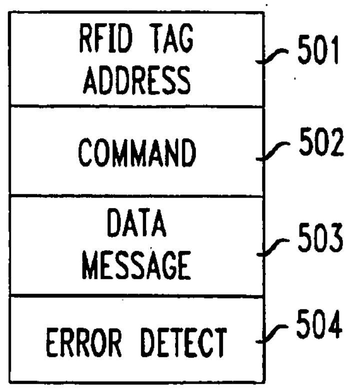
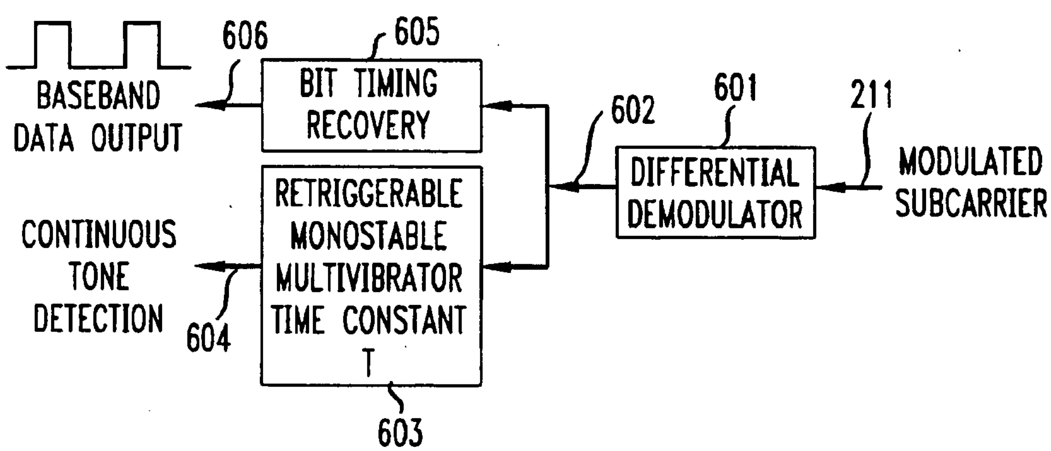
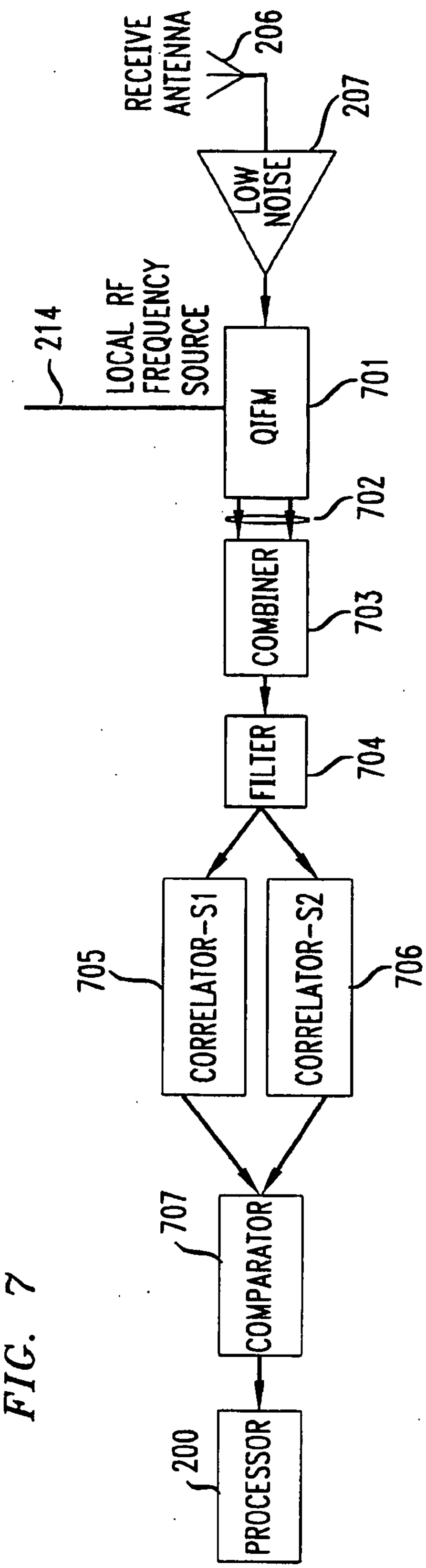

RFID TAG ADDRESS
501
COMMAND
502
DATA MESSAGE
503
ERROR DETECT
504

FIG. 6


BASEBAND DATA OUTPUT
606
605
BIT TIMING RECOVERY
RETRIGGERABLE MONOSTABLE MULTIVIBRATOR TIME CONSTANT T
CONTINUOUS TONE DETECTION
604
603
602
601
DIFFERENTIAL DEMODULATOR
211
MODULATED SUBCARRIER



RECEIVE ANTENNA
206
207
LOW NOISE
214
LOCAL RF FREQUENCY SOURCE
QIFM
701
702
COMBINER
703
FILTER
704
CORRELATOR-S1
705
CORRELATOR-S2
706
707
COMPARATOR
200
PROCESSOR

FIG. 7

DUAL MODE MODULATED BACKSCATTER SYSTEM

RELATED APPLICATIONS

Related subject matter is disclosed in the following application filed concurrently herewith and assigned to the same Assignee hereof: U.S. patent application Ser. No. 08/492,174, entitled "Full Duplex Modulated Backscatter System," inventors John A. MacLellan, R. Anthony Shober, Giovanni Vannucci, and Gregory A. Wright.

FIELD OF THE INVENTION

This invention relates to wireless communication systems and, more particularly, to a wireless communication system using modulated backscatter technology.

BACKGROUND OF THE INVENTION

Radio Frequency Identification (RFID) systems are used for identification and/or tracking of equipment, inventory, or living things. RFID systems are radio communication systems that communicate between a radio transceiver, called an Interrogator, and a number of inexpensive devices called Tags. In RFID systems, the Interrogator communicates to the Tags using modulated radio signals, and the Tags respond with modulated radio signals. Most commonly, this communication utilizes Time-Division Duplex (TDD) or Half Duplex techniques. After transmitting the message to the Tag (called the Downlink), the Interrogator then transmits a Continuous-Wave (CW) radio signal to the Tag. The Tag then modulates the CW signal using modulated backscattering where the antenna is electrically switched, by the modulating signal, from being an absorber of RF radiation to being a reflector of RF radiation. This modulated backscatter allows communications from the Tag back to the Interrogator (called the Uplink).

Prior art Modulated Backscatter (MBS) technology is described in U.S. Pat. Nos. 4,075,632, issued Feb. 21, 1978 to H. A. Baldwin et al. and entitled "Interrogation, And Detection System," and 4,360,810, issued Nov. 23, 1982 to J. A. Landt and entitled "Multichannel Homodyne Receiver". MBS systems typically utilize the amplitude modulated techniques described above for communications from the Interrogator to the Tag, and utilize MBS for communications from the Tag to the Interrogator.

RFID applications exist which have different data rate and range requirements. To accomplish great range, the data rate, especially in the Uplink, must be reduced. This is accomplished by backscatter modulating an unmodulated subcarrier onto a received CW signal for a duration of a few tenths of a second. The Interrogator then listens for an unmodulated tone on the reflected CW signal after the CW signal has undergone homodyne detection.

In order to implement higher bit rates, the Tag would generate an information signal, modulate that information signal upon a subcarrier, and use that modulated subcarrier to backscatter modulate the CW radio signal. In the Interrogator, after detection, the information signal is then demodulated from the subcarrier signal.

Undesirably, such prior art RFID systems are generally "single mode", in the sense that the Tag is capable of operating at either long range mode or higher bit rate mode rather than being capable of operating in both modes.

SUMMARY OF THE INVENTION

In accordance with the present invention, a radio communication system includes an Interrogator for generating and transmitting a first modulated signal by modulating a first information signal onto a radio carrier signal, the first information signal indicating in which of multiple response modes a receiving Tag should respond. One or more Tags of the system receive the first modulated signal and decode it to obtain the first information signal. A Backscatter Modulator modulates the reflection of the first modulated signal using a second information signal whose content, data rate, or modulation is determined by the first information signal, thereby forming a reflected second modulated signal. The Interrogator receives and demodulates the second modulated signal to obtain the indicated second information signal.

BRIEF DESCRIPTION OF THE DRAWING

In the drawing,

FIG. 1 shows a block diagram of an illustrative Radio Frequency Identification (RFID) system;

FIG. 2 shows a block diagram of an illustrative Interrogator Unit used in the RFID system of FIG. 1;

FIG. 3 shows a block diagram of a Tag Unit used in the RFID system of FIG. 1;

FIG. 4 shows a block diagram of an alternate embodiment of a Tag Unit used in the RFID system of FIG. 1;

FIG. 5 shows the Downlink message format;

FIG. 6 shows Interrogator receiver circuits for demodulating differential encoded modulated subcarrier signals; and

FIG. 7 shows Interrogator receiver circuits for demodulating pseudorandom codes encoded in the modulated subcarrier signals.

DETAILED DESCRIPTION

There are RFID system applications which have very different data rate requirements for the Downlink (Interrogator to Tag) and the Uplink (Tag to Interrogator) directions. One such class of applications involves using RFID technology to read information from a Tag affixed to a container or pallet. In this application, the container is moved (e.g., by being pulled by a small truck) across the reading field of an Interrogator. The reading field is defined as that volume of space within which a successful transaction can take place. While the Tag is in the reading field, the Interrogator to Tag transaction must be completed. Since the Tag is moving through the reading field, the RFID system has only a limited amount of time to successfully complete the transaction.

In such an application, the Tag could be moving as fast as 10 meters/second through the reading field. The reading field would consist of a roughly conical volume, extending 5 meters away from the Interrogator, and the cone having an angle of roughly 60 degrees total spread (30 degrees to either side of a direct path from the Interrogator to a point immediately in front of the Interrogator). Given this situation, the RFID communications with each Tag must be completed in less than 0.5 seconds.

Therefore, effective RFID systems must be able to a) have the Tag detect the presence of the Interrogator in a very short period of time, and b) have the Tag to Interrogator data rate be sufficiently large such that the communications can be completed within the time period available. Furthermore, the system must work even if several Tags are in the reading field at the same time. Given these constraints, an Uplink data rate of 50 Kbps, or perhaps greater, may be desirable.

Other application of this RFID system calls for the Tag to be interrogated at distances significantly greater than 5

meters, with the same downlink signal used by short-range Interrogators. To support this greater range, the Downlink data rate must be limited to keep the signal-to-noise ratio acceptable. An example of these alternative applications was discussed in pending U.S. patent application Ser. No. 08/206,075, entitled "Modulated Backscatter Wireless Communication System Having An Extended Range," now abandoned in which Tags were used as Electronic Shelf Labels to display correct prices on a supermarket shelf. In this application, Downlink data rates of about 1 Kbps are used.

Therefore, an object of the present invention is an RFID system that achieves synchronization rapidly, even with a relatively low-speed Downlink and having a relatively high-speed Uplink to send the necessary Tag data rapidly even in the presence of multiple Tags in the reading field.

With reference to FIG. 1, there is shown an overall block diagram of an illustrative RFID system useful for describing the application of the present invention. An Applications Processor **101** communicates over Local Area Network (LAN) **102** to a plurality of Interrogators **103–104**. The Interrogators may then each communicate with one or more of the Tags **105–107**. For example, the Interrogator **103** receives an information signal, typically from an Applications Processor **101**. The Interrogator **103** takes this information signal and Processor **200** properly formats a Downlink message (Information Signal **200*a***) to be sent to the Tag. With joint reference to FIGS. 1 and 2, Radio Signal Source **201** synthesizes a radio signal, the Modulator **202** modulates this Information Signal **200*a*** onto the radio signal, and the Transmitter **203** sends this modulated signal via Antenna **204**, illustratively using amplitude modulation, to a Tag. The reason amplitude modulation is a common choice is that the Tag can demodulate such a signal with a single, inexpensive nonlinear device (such as a diode).

In the Tag **105** (see FIG. 3), the Antenna **301** (frequently a loop or patch antenna) receives the modulated signal. This signal is demodulated, directly to baseband, using the Detector/Modulator **302**, which, illustratively, could be a single Schottky diode. The diode should be appropriately biased with the proper current level in order to match the impedance of the diode and the Antenna **301** such that losses of the radio signal are minimized. The result of the diode detector is essentially a demodulation of the incoming signal directly to baseband. The Information Signal **200*a*** is then amplified, by Amplifier **303**, and synchronization recovered in Clock Recovery Circuit **304**. The Clock Recovery Circuit **304** can be enhanced by having the Interrogator send the amplitude modulated signal using Manchester encoding. The resulting information is sent to a Processor **305**. The Processor **305** is typically an inexpensive 4 or 8 bit microprocessor; the Clock Recovery Circuits **304** can be implemented in an ASIC (Application Specific Integrated Circuit) which works together with Processor **305**. This Processor **305** can also serve as the driver for an optional Display Unit **309** should this Tag require a display. The Processor **305** generates an Information Signal **306** to be sent from the Tag **105** back to the Interrogator (e.g., **103**). This Information Signal **306** is sent to a Modulator Control Circuit **307**, which uses the Information Signal **306** to modulate a subcarrier frequency generated by the subcarrier Frequency Source **308**. The Frequency Source **308** could be a crystal oscillator separate from the Processor **305**, or it could be a frequency source derived from signals present inside the Processor **305**—such as a multiple of the fundamental clock frequency of the Processor. The Modulated Subcarrier Signal **311** is used by Detector/Modulator **302** to modulate the modulated signal received from Tag **105** to produce a modulated backscatter (i.e., reflected signal). This is accomplished by switching on and off the Schottky diode using the Modulated Subcarrier Signal **311**, thereby changing the reflectance of Antenna **301**. A Battery **310** or other power supply provides power to the circuitry of Tag **105**.

There are a variety of techniques for using Modulated Backscatter (MBS) to send information from the Tag to the Interrogator. In some MBS technologies, the Modulator Circuit **307** of the Tag generates an amplitude modulated signal modulated by an Information Signal **306** at frequency f_2. If the Radio Signal Source **201** generates an unmodulated frequency f_1, then the Interrogator receives signals inside of the range (f_1-f_2) to (f_1+f_2), and filters out signals outside of that range. This approach could be termed the "MBS at baseband" approach. Another approach would be for the Tag to generate two subcarrier frequencies, generated by Frequency Sources **401** and **402**, as shown in FIG. 4. The information could be conveyed in a frequency-shift keyed (FSK) fashion with the subcarrier frequency transitioning between these two frequencies. Other modulation schemes are possible as well, such as phase shift keying (PSK) of a single subcarrier frequency (e.g., BPSK, QPSK) or other complex modulation schemes (e.g., MFSK, MASK, etc.).

Returning to FIG. 2, the Interrogator **103** receives the reflected and modulated signal with the Receive Antenna **206**, amplifies the signal with a Low Noise Amplifier **207**, and demodulates the signal using homodyne detection in a Quadrature Mixer **208**. (In some Interrogator designs, a single Transmit (**204**) and Receive (**206**) Antenna is used. In this event, an electronic method of canceling the transmitted signal from that received by the receiver chain is needed; this could be accomplished by a device such as a Circulator.) Using the same Radio Signal Source **201** as used in the transmit chain means the demodulation to IF is done using Homodyne detection; this has advantages in that it greatly reduces phase noise in the receiver circuits. The Mixer **208** then sends the Demodulated Signal **209** (if a Quadrature Mixer, it would send both I (in phase) and Q (quadrature) signals) into the Filter/Amplifier **210**. The resulting filtered signal—then typically an Information Signal **211** carried on an IF subcarrier—is then demodulated from the subcarrier in the Subcarrier Demodulator **212**, which then sends the Information Signal **213** to a Processor **200** to determine the content of the message. The I and Q channels of Signal **209** can be combined in the Filter/Amplifier **210**, or in the Subcarrier Demodulator **212**, or they could be combined in the Processor **200**. Common practice would utilize error detection in both messages sent over the link from the Interrogator **103** to the Tag **105**, and also over the link from the Tag **105** to the Interrogator **103**.

Using the above techniques as an example, an inexpensive, short-range, bi-directional digital radio communications channel is implemented. These techniques are inexpensive as the components consist of (for example) a Schottky diode, an amplifier to boost the signal strength, bit and frame synchronization circuits, an inexpensive 4 or 8 bit microprocessor, subcarrier generation circuits, and a battery. Most of these items are already manufactured in quantities of millions for other applications, and thus are not overly expensive. The circuits mentioned above for bit and frame synchronization and for subcarrier generation can be implemented in custom logic surrounding the microprocessor core; thus, except for a relatively small amount of chip real estate, these functions come almost "for free." Such circuitry is, illustratively, described in the previously filed applications of Ser. No. 08/206/075, now abandoned and U.S. patent application Ser. No. 08/409,782, now U.S. Pat. No.

5,598,169 entitled "Detector and Modulator Circuits for Passive Microwave Links.

In accordance with the present invention, a Tag unit of an RFID system has the capability to operate in a "dual mode" fashion. The Tag, based upon a command from the Interrogator, responds to the Interrogator with either a "single tone" acknowledgment (to achieve great range) or with an information signal (for greater data rates at lesser range). The RFID system of the present invention may communicate using the well-known Time-Division Duplex (TDD), Half Duplex or Full Duplex techniques disclosed in the previously identified related application concurrently filed herewith.

The basic features of this invention are that a) the Tag must be capable of receiving a Downlink message; b) the Tag must be told what type of Uplink message it is to transmit, whether it be an actual data message (higher bit rate mode) or a "single tone" acknowledgment message (long range mode), based upon information received in the Downlink message; c) the Tag transmits the requested type of Uplink message; and d) the Interrogator interprets the Uplink message received in a proper manner. Several different types of acknowledgment messages in the long range mode can exist. Generally, an acknowledgment message has a data rate which is much less than the data rate of an actual data message (the higher bit rate mode), thus allowing filtering over a much smaller frequency band, and thus allowing greater range than the higher bit rate mode since the noise bandwidth of the received signal is lessened due to the narrowband filtering. Thus, an acknowledgment message could consist of a low bit rate data message, or it could consist of a single bit of information. To send a single bit of information, the Tag could generate an unmodulated subcarrier frequency which could be modulated onto the incident signal, using modulated backscatter. The Interrogator would then receive a reflected signal with a single frequency tone. Narrowband filtering techniques could then be used to reduce the noise bandwidth and determine the presence or absence of this signal.

The Tag **105** detects and assembles the bits of information sent from the Interrogator **103** into a complete Downlink message. Typically, a pattern of synchronization bits is transmitted at the beginning of the Downlink message; these bits allow the Tag to acquire bit and message synchronization; enabling the Tag to determine the beginning and the end of the Downlink message. Well known synchronization techniques may be utilized, including the methods described in the previously identified copending application. Once the Downlink message is assembled, it may be of the form shown in FIG. **5**. The RFID Tag Address **501** is the address of the Tag **105** to which the Interrogator **103** wishes to communicate. To keep the number of bits in the RFID Tag Address **501** as small as possible, this address might be a hashed index into a longer table of tag addresses. Then, the Interrogator **103** would have a certain probability of addressing the correct tag. The Command data **502** includes bits which direct the Tag to perform the correct function. For example, if data were to be stored on the Tag **105**, the data could be sent in the Data Message field **503**. The accuracy of the data could be insured by an Error Detect field **504**. The Command data **502** or Data Message **503** portion of the Downlink message could indicate that the Tag **105** should return a Message to the Interrogator; for example, the Tag could return stored data, such as the Tag ID, or other application-specific data. Another type of Downlink message could indicate that the Tag should send back only a single-bit acknowledgment message.

Thus, the Processor **305** of the Tag **105** determines, in response to information in the Downlink message, what type of Uplink signal to transmit: a data message or a "single tone" acknowledgment message. There are several ways that the Tag **105** may transmit either a data message (or information signal) or a single-bit acknowledgment message so that the Interrogator **103** can, relatively easily, receive and distinguish between these two different types of messages. Referring to FIG. **3**, in the event that the Tag **105** is to send a multi-bit information signal, Processor **305** sends the Information signal to the Modulator Control **307**, which modulates the signal from Subcarrier Frequency Source **308**. The selection of the actual subcarrier frequency of the Frequency Source **308** is done with some care.

As disclosed in the previously referenced patent application 08/206,075, MBS systems exhibit noise in the Uplink signals due to reflections of the RF source from any number of reflectors. Walls and metal objects reflect RF radiation; these reflected signals are received by the Interrogator **103** at the same carrier frequency as they were transmitted. The Quadrature Mixer **208** is operated as a Homodyne Detector and thus is used to cancel these reflections. However, other reflectors generate reflected noise at frequencies away from the main carrier frequency—either from Doppler shifts or, more likely, from reflections off of electronic equipment operating at frequencies near the Subcarrier Frequency. One particularly difficult source of noise are fluorescent lights, which have been shown to produce noise not only at their fundamental 60 Hz (in the United States) frequency, but also at overtone frequencies well up into the tens of thousands of Hertz. The use of subcarrier frequencies that are above 50–100 KHz are especially useful in avoiding this noise.

In Tag **105**, Processor **305** sends the Information Signal over the Information Signal Lead **306** shown in FIG. **3**. In the event that Processor **305** of Tag **105** is to send a "single tone" message consisting of a single information bit, the Information Signal Lead **306** is maintained at a first logic state to indicate that no information message is to be sent. Thus, an unmodulated subcarrier frequency signal is outputted by Modulator Control **307**. In the event that Processor **305** determines that a multi-bit message is to be sent, the Information Signal Lead **306** conveys the multi-bit message to Modulator Control **307**. This multi-bit message (information signal) is then used to modulate the subcarrier frequency using one of several possible modulation techniques, such as amplitude, phase, frequency, or code modulation.

According to another embodiment (see Lead **312** of FIG. **3**), Processor **305** may itself generate a subcarrier frequency modulated with the multibit information signal. In this case, for Processor **305** to send out a pure subcarrier frequency, the Processor will clock out, from an I/O port, the bit pattern "**01010 101**", with the zeroes and ones being clocked out at a rate of $2r_b$ clocks per second. This pattern generates a pure subcarrier signal at a frequency of r_b cycles per second. In order to clock out an Information message, the Processor **305** clocks out a variant of the above bit pattern. For example, assume that Processor **305** is to clock out a Binary Phase Shift Keying (BPSK) modulated signal. Let r_i be the information data rate, and let r_b be the frequency of the subcarrier signal, as shown above. Assuming, for simplicity, that r_b is an integer multiple of r_i, then r_b/r_i is the number of "01" cycles that would be sent during one information bit period. To send BPSK, Processor **305** sends r_b/r_i repetitions of "01", followed by r_b/r_i repetitions of "10". This represents a binary phase change.

To clock out a Quadrature Phase Shift Keying (QPSK) signal, Processor **305** sends out $r_b/2r_i$ repetitions of one of

the four QPSK symbols, such as "0110 0110 . . . 0110", and then clocks out the same number of repetitions of the next symbol to be transmitted.

Finally, Processor **305** could also clock out pseudorandom sequences. For example, define two sequences of $2r_b/r_i$ bits and refer to these as sequences S_1 and S_2. Then, the Tag **105** transmits S_1 as a "0" information bit and S_2 as a "1" information bit. The use of pseudorandom sequences may be very beneficial over the above BPSK or QPSK examples in the event that the radio environment has impairments such as multipath fading or narrowband interferers. Considering the frequency and severity of these fades, it may be helpful to spread the Uplink signal in order for the Uplink path to be more resistant to such fades. The two sequences, S_1 and S_2, should be chosen to be nearly orthogonal.

The Interrogator **103** (FIG. **2**) demodulates the subcarrier signal from the received RF signal, and then applies filtering. Given the specifics of the subcarrier frequency, a suitable filtering amplifier is utilized. Subcarrier Demodulator **212** then demodulates the subcarrier signal. The Processor **200** then performs the digital signal processing necessary to decode the information. In some implementations of this invention, the Processor may be a Digital Signal Processor (DSP); in others, a conventional Microprocessor could be used. To recover a "single tone" acknowledge signal from Tag **105**, consisting of a single subcarrier tone, the filtering amplifier would be a narrowband filter. While conventional filter technologies could be used, it may be most effective to utilize the DSP mentioned above as a narrowband filter. The subcarrier frequency of this single tone is well known; as the Tag **105** would typically use an inexpensive crystal as the frequency source. Even with the limited accuracy of that crystal, the subcarrier frequency could be known to an accuracy of a few Hertz. Thus, very narrowband filters could be used. Since the acknowledge signal response from Tag **105** is used to extend the range of the RFID system and consequently would likely be a very faint signal, it places an additional burden on the narrowband filter of filtering amplifier **210**.

Another way that the DSP mentioned above could be used is to dynamically search for the frequency components of the Uplink signal. This could be accomplished by performing a Fourier Transform on the incoming data stream, perhaps using a DSP, or using Processor **200** of FIG. **2**. In this manner, the multiple signals representing a modulated subcarrier signal could be differentiated; or, a single subcarrier signal of uncertain data rate could be recovered by using the Fourier Transform to search for multiple signals.

Thus, the modulated backscatter communication system of the present invention can operate in two modes—one in which the backscattered signal is modulated to provide a high data rate Uplink communication channel, and one in which the backscattered channel is modulated with a low data rate signal, perhaps a single tone, to provide an Uplink acknowledgment signal that can be detected at great distances. In another system arrangement, we disclose a method for building a demodulator/symbol synchronization and recovery unit to handle both modes. This arrangement works for a backscatter communication system using a phase modulated subcarrier with differential encoding. Differential encoding means that the data is encoded in the changes in the subcarrier phase. A continuous tone subcarrier is therefore equivalent to the bit sequence {0, 0, 0 . . . }.

Shown in FIG. **6** is an Interrogator **103** having receiver circuits for demodulating the differentially encoded subcar-

rier signal. When a modulated carrier **211** is fed into the differential demodulator **601**, the demodulator **601** output is a baseband data stream **602**. When the baseband data stream has **0** to **1** and **1** to **0** transitions frequently enough, the retriggerable monostable multivibrator **603** is continually re-triggered, and its output **604** does not change. If, however, the demodulator **601** output has a string of **0**'s or **1**'s that last longer than the monostable's **603** time constant T, the monostable's output **604** changes, signaling the presence of the string of **0**'s or **1**'s (a long string of **0**'s or **1**'s indicates the presence of a continuous tone at the input of the demodulator **601**). The Bit Timing Recovery Circuit **605** generates the baseband data output signal **606**.

When there is no subcarrier signal present at the demodulator input, assume that the Demodulator **601** produces random output with transitions typically much more frequently than the time period T, so the Monostable **603** is continuously re-triggered. This means that the Interrogator **103** can distinguish a "no signal present" condition from a "constant tone present" condition at the demodulator output.

Note that the retriggerable monostable **603** is only one possible implementation of this idea. More sophisticated statistics could be performed on the demodulator input **211** to detect a possibly weak tone in a noisy background. In one embodiment, the Processor **200** of Interrogator **103** is used to implement the Bit Timing Recovery Circuit **605** and Monostable Circuit **603**.

For the case in which the Tag is sending two pseudorandom sequences, the receiver circuits of Interrogator **103** of FIG. **2** are modified as follows in FIG. **7**. The Receive Antenna **206** receives the modulated radio frequency signal which is then amplified by Low Noise Amplifier **207** and demodulated by Quadrature Mixer (QIFM) **701**. The I and Q channel signals **703** outputted from QIFM **701** are combined (square root of the sum of the squares) in Combiner **703**, then filtered by Filter **704**, and then the result sent into two Correlators **705** and **706**, one for pattern S_1 and one for pattern S_2. The outputs of the Correlators **705** and **706** are sent to a Comparator **707** to determine if the result is a "0" or a "1" signal. The output of the Comparator **707** is then sent to the Processor **200** to perform Uplink message synchronization.

What has been described is merely illustrative of the application of the principles of the present invention. Other arrangements and methods can be implemented by those skilled in the art without departing from the spirit and scope of the present invention.

We claim:

1. A radio communication system comprising

an interrogator including

means for generating a first modulated signal by modulating a first information signal onto a radio carrier signal, said first information signal indicating to which of multiple response modes a receiving tag should respond,

means for transmitting said first modulated signal to said at least one tag,

said at least one tag including

means for receiving said first modulated signal,

means for decoding said first modulated signal to obtain said first information signal,

backscatter modulator means for modulating a reflection of said first modulated signal using a second information signal whose content, data rate, or modulation is determined from the contents of said first information signal, thereby forming a reflected second modulated signal,

said interrogator further including
means for receiving said second modulated signal, and
means for demodulating said second modulated signal, to obtain said second information signal, whose content, data rate, or modulation was determined from the contents of said first information signal.

2. The radio communication system of claim 1 wherein said first modulated signal is generated using a first modulation type selected from a group including at least amplitude, phase, frequency, time-division, and code-division modulation types.

3. The radio communication system of claim 1 wherein the interrogator demodulating means includes a homodyne detector and uses said first modulated signal as the frequency source input to said detector.

4. The radio communication system of claim 1 wherein said first information signal indicates which of a first mode, including a data message in said second information signal, and a second mode, including an acknowledgment message in said second information signal, that said at least one tag should respond.

5. The radio communication system of claim 4 wherein said second information signal consists of a single bit of information.

6. The radio communication system of claim 5 wherein said single bit of information is communicated by the presence or absence of a single subcarrier tone backscatter modulating said first modulated signal.

7. The radio communication system of claim 1 when said at least one tag responds in said first mode, wherein
the bits of information contained within said second information signal are differentially encoded, and wherein
said demodulating means demodulates the differentially encoded bits to recover the data within said second information signal.

8. The radio communication system of claim 1 when said at least one tag responds in said second mode, wherein
the bits of information contained within said second information signal are differentially encoded, and wherein
said demodulating means demodulates the differentially encoded bits to recover the data within said second information signal.

9. The radio communication system of claims 7 or 8, wherein said interrogator includes
means for providing a retriggerable monostable multivibrator function to detect the acknowledgment message.

10. The radio communication system of claim 1 wherein said interrogator includes
processor means for performing a Fourier Transform to obtain said second information signal.

11. A tag for use in a radio communication system comprising
means for receiving said first modulated signal,
means for decoding said first modulated signal to obtain said first information signal, said first information signal indicating in which of multiple response modes a receiving tag should respond,
backscatter modulator means for modulating the reflection of said first modulated signal using a second information signal whose content, data rate, or modulation is determined by said first information signal, thereby forming a reflected second modulated signal.

12. A radio communication system comprising
an interrogator including
means for generating a first modulated signal by modulating a first information signal onto a radio carrier signal, said first information signal indicating which of multiple response modes a receiving tag should respond,
means for transmitting to said at least one tag during a first time interval said first modulated signal, and transmitting said radio carrier signal during a second time interval,
said at least one tag including
means for receiving said radio carrier signal and said first modulated signal,
means for decoding said first modulated signal to obtain said first information signal,
backscatter modulator means for modulating the reflection, during said second time interval, of said radio carrier signal using a second information signal whose content, data rate, or modulation is determined from the contents of said first information signal, thereby forming a reflected second modulated signal,
said interrogator further including
means for receiving said second modulated signal, and
means for demodulating said second modulated signal, to obtain said second information signal, whose content, data rate, or modulation was determined from the contents of said first information signal.

13. The radio communication system of claim 12 wherein said first information signal indicates which of a first mode, including a data message in said second information signal, and a second mode, including an acknowledgment message in said second information signal, that said at least one tag should respond.

14. The radio communication system of claim 13 wherein said second information signal consists of a single bit of information.

15. The radio communication system of claim 14 wherein said single bit of information is communicated by the presence or absence of a single subcarrier tone backscatter modulating said radio carrier signal.

16. The radio communication system of claim 12 when said at least one tag responds in said first mode, wherein
the bits of information contained within said second information signal are differentially encoded, and wherein
said demodulating means demodulates the differentially encoded bits to recover the data within said second information signal.

17. The radio communication system of claim 12 when said at least one tag responds in said second mode, wherein
the bits of information contained within said second information signal are differentially encoded, and wherein
said demodulating means demodulates the differentially encoded bits to recover the data within said second information signal.

18. The radio communication system of claims 16 or 17, wherein said interrogator includes
means for providing a retriggerable monostable multivibrator function to detect the acknowledgment message.

19. The radio communication system of claim 12 wherein said interrogator includes
processor means for performing a Fourier Transform to obtain said second information signal.

20. The radio communication system of claim 12 wherein said first modulated signal is generated using a first modu-

lation type selected from a group including at least amplitude, phase, frequency, time-division, and code-division modulation types.

21. The radio communication system of claim 12 wherein the interrogator demodulating means includes a homodyne detector and uses said radio carrier signal as the frequency source input to said detector.

22. A method of operating a radio communication system comprising the steps of

at an interrogator

generating a first modulated signal by modulating a first information signal onto a radio carrier signal, said first information signal indicating which of multiple response modes a receiving tag should respond,

transmitting said first modulated signal to said at least one tag;

at said at least one tag

receiving said first modulated signal,

decoding said first modulated signal to obtain said first information signal,

modulating, using a backscatter modulator, a reflection of said first modulated signal using a second information signal whose content, data rate, or modulation is determined from the contents of said first information signal, thereby forming a reflected second modulated signal;

at said interrogator

receiving said second modulated signal, and

demodulating said second modulated signal, to obtain said second information signal, whose content, data rate, or modulation was determined from the contents of said first information signal.

23. A method of operating a tag for use in a radio communication system comprising the steps of

receiving a first modulated signal,

decoding said first modulated signal to obtain said first information signal, said first information signal indicating in which of multiple response modes a receiving tag should respond,

modulating, using a backscatter modulator, a reflection of said first modulated signal using a second information signal whose content, data rate, or modulation is determined by said first information signal, thereby forming a reflected second modulated signal.

24. A method of operating a radio communication system comprising the steps of

at an interrogator

generating a first modulated signal by modulating a first information signal onto a radio carrier signal, said first information signal indicating which of multiple response modes a receiving tag should respond,

transmitting to said at least one tag during a first time interval said first modulated signal, and transmitting said radio carrier signal during a second time interval;

at said at least one tag

receiving said radio carrier signal and said first modulated signal,

decoding said first modulated signal to obtain said first information signal,

modulating, using a backscatter modulator, a reflection, during said second time interval, of said radio carrier signal using a second information signal whose content, data rate, or modulation is determined from the contents of said first information signal, thereby forming a reflected second modulated signal;

at said interrogator

receiving said second modulated signal, and

demodulating said second modulated signal, to obtain said second information signal, whose content, data rate, or modulation was determined from the contents of said first information signal.

25. A tag for use in a radio communication system comprising

means for receiving a radio carrier signal and a first modulated signal,

means for decoding said first modulated signal to obtain said first information signal, said first information signal indicating in which of multiple response modes a receiving tag should respond,

backscatter modulator means for modulating the reflection of said radio carrier signal using a second information signal whose content, data rate, or modulation is determined by said first information signal, thereby forming a reflected second modulated signal.

26. A method of operating a tag for use in a radio communication system comprising the steps of

receiving a radio carrier signal and a first modulated signal,

decoding said first modulated signal to obtain said first information signal, said first information signal indicating in which of multiple response modes a receiving tag should respond,

modulating, using a backscatter modulator, a reflection of said radio carrier signal using a second information signal whose content, data rate, or modulation is determined by said first information signal, thereby forming a reflected second modulated signal.

* * * * *

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United States Patent [19]

Forster

[11] **Patent Number: 6,046,668**

[45] **Date of Patent: Apr. 4, 2000**

[54] **INTERROGATOR CIRCUIT ARRANGEMENT**

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[22] Filed: **Aug. 7, 1997**

[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[7] **H04Q 1/00**

[52] **U.S. Cl.** **340/10.4**; 340/572.2

[58] **Field of Search** .... 340/825.54, 825.69, 340/825.71, 825.16, 505, 572.2, 572.5; 342/175, 42; 367/2, 6; 455/333, 318, 327, 326; 331/58, 65, 108 R, 117 FE, 187; 1/1

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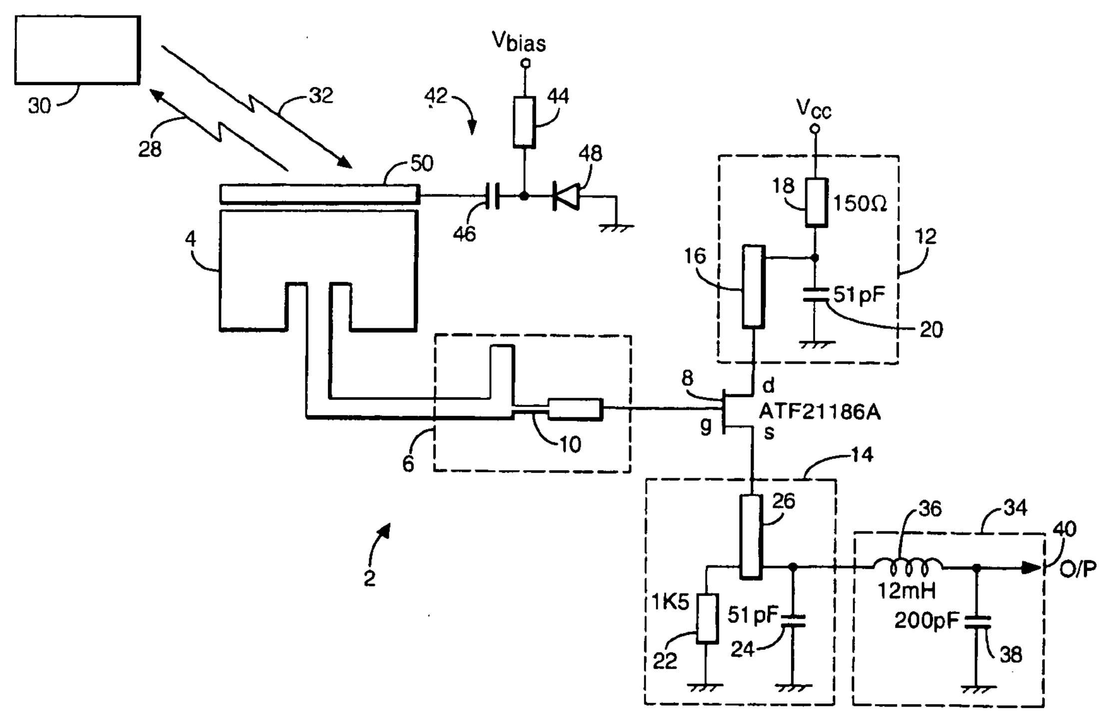
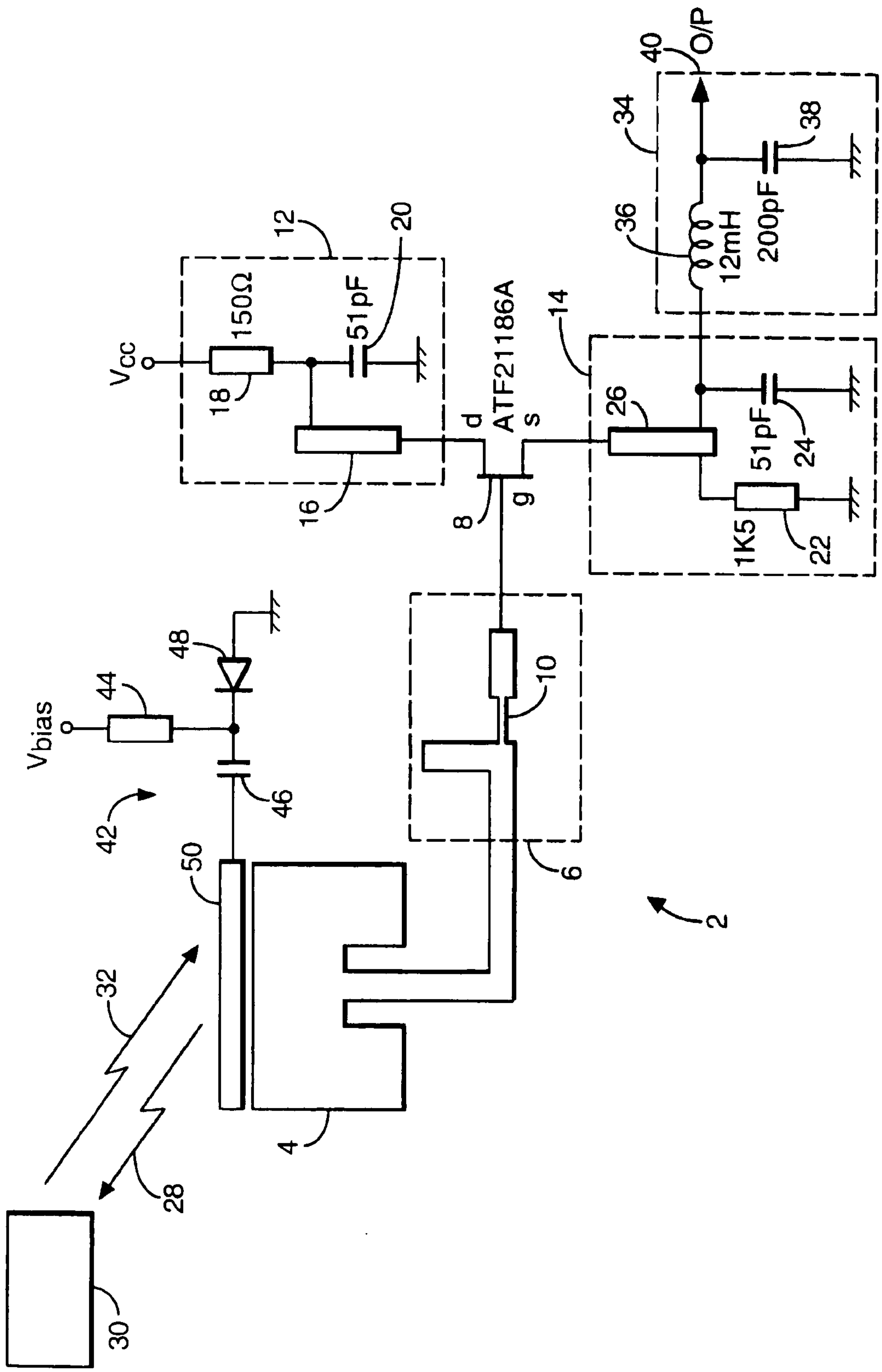
Attorney, Agent, or Firm—Donald C. Casey, Esq.

[57] **ABSTRACT**

An interrogator circuit (**2**) for use with a semi-passive transponder (**30**) of a type which reflectively modulates an incoming signal (**28**) is described. The circuit (**2**) comprises an antenna (**4**), a transistor (**8**), a matching network (**6**) connecting to the antenna (**4**) to an input of the transistor and means (**12, 14**) for operating the transistor such that it self-oscillates and radiates power (**28**) from the antenna (**4**) and simultaneously acts as a self-oscillating mixer to produce an output (**40**) which is representative of the modulation of a signal **32** received at the antenna. For an efficient conversion gain the reflection coefficient of the antenna (**4**) is configured to be low when the circuit is in a stable self-oscillating condition.

13 Claims, 1 Drawing Sheet

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26
51pF
24
16
g
8
1K5
22
48
44
Vbias
10
46
42
50
6
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32
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28
30

INTERROGATOR CIRCUIT ARRANGEMENT

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an interrogator circuit for use in a tagging system which has tags including a semi-passive or reflective modulating transponder.

2. Description of the Related Art

The application of tagging systems using transponder circuits is becoming increasingly widespread. Tagging systems generally comprise a number of integrator circuits which are connected to a control centre by means of a communications network and a number of tags with which the interrogator can communicate typically by means of radio links. Generally an interrogator circuit is at a fixed location whilst the tags are fitted to objects which are mobile.

One example of a tagging system is a road tolling system in which vehicles are fitted with a transponder (tag) which can be interrogated by interrogating circuits which are situated at toll collection points around the road network. Communication between the vehicle and the interrogating circuit provides the requisite tolling information for charging the road user. The applications for tagging systems are virtually limitless, for example in the field of telematics, that is, the communication between an infrastructure and vehicles, it has been proposed to use such tags in the translation of road signs, for routing information and bus priority schemes to name but a few. Other applications include logistics, for example keeping tack of the movements of goods such as food between a warehouse and a number of retail outlets. In all of these applications the transponder circuit which typically operates at microwave frequencies, needs to be inexpensive and have a long opening life. To meet the former require the circuitry to be simple, whilst the latter generally requires the circuit to have low power consumption and be capable of operating from a battery source.

Transponder circuits for tags may be "active", that is it includes its own radio transmitter and is able to transmit without the assistance of the interrogator circuit, purely "passive" that is they can be read by an interrogator but cannot themselves talk to the interrogator circuit, or be what is termed semi-passive. Semi-passive transponders can detect data transmitted to them from the interrogator and transmit information to the interrogator by reflecting and modulating the signal received from the interrogator. As such, semi-passive transponders do not include an active transmitter and rely solely on the interrogator to provide the communication medium. Such transponders are also often referred to as reflective modulator type transponders. Since such transponders require minimal radio frequency circuitry the tags are compact and have very low power consumption making them ideally suited to many tagging applications. The present invention relates to an interrogator circuit which is suitable for use with semi-passive transponders. This requires the interrogator circuit to be cable of transmitting a signal and simultaneously demodulating a received signal.

The suitability of tagging systems to a given application is at present largely limited by the cost of the interrogator circuit and tag transponder. Whilst much time and effort has been expended in developing efficient, inexpensive semi-active tag transponders the interrogator circuits remain relatively complex and expensive. Usually a separate receiver and transmitter circuit are provided which may or may not use a common antenna. Often these circuits include double balanced mixers which are configured as an image reject front end and have I and Q baseband receivers. Whilst such interrogator circuits are found to work very effectively in terms of range and robustness they have an associated problem that their production cost is high, typically of the order of a few hundred pounds. A number of applications exist for a much lower cost interrogator circuit which is capable of operating at a moderate range, typically ten metres or so. In addition to the need for an inexpensive interrogator, a whole new range of applications arises if the interrogator circuit could be operated from a battery source. At present, whilst the tags have very low power consumption, the interrogator, which is typically located at a fixed location and has the benefit of a mains power supply available, has a relatively high power consumption. A need therefore exists for an interrogator circuit for use with semi-passive transponders which has very low power consumption and can be effectively operated from a battery supply over a long period of time.

SUMMARY OF THE INVENTION

According to a first aspect of the invention an interrogator circuit for use with a semi-passive transponder comprises: a transistor configured in operation to self oscillate and simultaneously act as a self oscillating mixer to detect modulation of a signal applied to an input of the transistor. Since the inventions only a single transistor the circuit is inexpensive, has very low power consumption and can be operated from a battery supply.

According to a further aspect of the invention there is provided an irrigator circuit for use with a transponder of a type which reflectively modulates a received signal, the interrogator circuit comprising: an antenna, a transistor, a matching network connecting the antenna to an input of the transistor and means for operating the transistor such that, it self-oscillates and radiates a signal from the antenna and simultaneously act as a self-oscillating mixer to produce an output which is representative of the modulation of a signal reflectivity modulated by the transponder.

In a particularly preferred embodiment the circuit is arranged such that the frequency of oscillation of the transistor is determined by the resonant frequency of the antenna. As the oscillation frequency is determined by the resonant frequency of the antenna this eliminates the need for additional frequency stabilization elements such as a dielectric resonator, thereby simplifying the circuit greatly. Furthermore since the oscillation frequency is denied by the resonant frequency of the antenna this ensures the conversions gain of the self oscillating mixer is high. This is because at resonance the return loss of the antenna will be low which ensures the reflection gain of the transistor remains high is a stable oscillatory condition.

Preferably the antenna is well matched to the transistor. In a preferred arrangement the interrogator circuit further comprises means for setting the resonant frequency of the antenna thereby enabling the frequency of operation of the circuit to be accurately set

Where it is required to operate the circuit at microwave frequencies the transistor conveniently comprises a field effect transistor, the antenna comprises a patch antenna and the matching circuit comprises a micro strip line.

Advantageously the interrogator circuit further comprises means for modulating the power radiated from the antenna enabling the circuit to communicate information to a semi-passive transponder. Preferably modulation of the signal is detected using a tuned circuit connected to the output of the transistor.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawing is a schematic of an interrogator circuit of this invention.

DESCRIPTION OF A PREFERRED EMBODIMENT

Referring to the drawing, there is shown an interrogator circuit 2 in accordance with the invention which comprises a patch antenna 4 configured for operation at 2.45 GHz. The antenna 4 is connected by a means of an impedance matching network 6 to the gate g of a field affect transistor (FET) 8. In the embodiment illustrated the FET 8 is a Gallium Arsenide FET ATF 21186A. For operation at 2.45 GHz the matching network 6 comprises a microstrip line arrangement 10 which matches the impedance of the FET 8 to that of the antenna 4 thereby ensuring the reflection coefficient, or return loss, of the antenna as seen from the FET 8 is low, typically of the order of −20 dB.

Respective bias and matching networks 12, 14 and provided at the drain d and source s of the FET 8. The bias and matching networks 12, 14 set the appropriate dc operating condition, bias condition, for the FET 8 and ensure that the FET 8 operates as a negative resistance; that is a signal applied to the gate g is reflected with increased magnitude. Conveniently, the bias and matching network 12 comprises a microstrip line 16, a resistor 18 and capacitor 20 as illustrated in the drawing. The bias and matching network 14 at the source s comprises a resistor 22, a capacitor 24 and microstrip line 26. It will be appreciated that the use of a particular bias and matching network is not essential to the invention and will depend on a given application, in particular, the required operating frequency which will largely determine the type of transistor/antenna required.

The FET 8 is configured by means of the bias and matching networks 12, 14 to ensure that when the circuit is initially powered-up, that is, the circuit is in a small signal condition, the reflection gain of the FET 8 is greater than the refection coefficient (return loss) of the antenna 4. As a consequence when the circuit is powered up any signal which is present at the gate will be reflected with increased magnitude towards the antenna 4. Since the reflection coefficient of the antenna 4 is lower than the reflection gain of the FET 8 the majority of the signal will be radiated by the antenna 4. However a very small proportion of the signal will be re-reflected by the antenna 4 back towards the gate g, in the example 1 dB. This proportion will be re-reflected and amplified by the FET 8 and a small portion subsequently reflected by the antenna 4. This process will continue such that the signal magnitude will increase until the circuit 2 reaches a stable oscillatory condition. In such a condition the reflection gain of the FET 8 becomes compressed and will equal the reflection coefficient (return loss) of the antenna 4. In this stable condition the circuit self-oscillates and radiates a continuous wave (cw) signal 28 at, or near to, 2.45 GHz The difference between the reflection gain and return loss in a small signal condition determines how quickly the circuit reaches a stable oscillatory condition.

If a reflective modulator type transponder (semi passive transponder) tag 30 is placed in the vicinity of the interrogator circuit 2 it will modulate and reflect the signal 28 to produce a modulated signal 32. The tag 30 modulates the continuous wave 28 incident upon it with information by generating a double sideband at, for example, a 100 kHz baseband. The modulated signal 32 is received by the antenna 4. The received 100 kHz sidebands are mixed with the transmitted signal 28, causing a baseband current to flow in the sourse, which drives a series tuned circuit 34. The tuned circuit 34 comprises an inductor 36 and a capacitor 38. The selection of these components 36, 38 is used to detect a signal to produce a demodulated sign at an output 40 of the required baseband frequency. In the example the circuit 34 is tuned for operation at 100 kHz

It will be appreciated that the interrogator circuit 2 operates to self-oscillate thereby transmitting a continuous wave signal 28 and is simultaneously capable of receiving and detecting a modulated signal 32 by functioning as a self-oscillating mixer. In doing so the semi-passive transponder tag 30 is able to communicate with the interrogator circuit 2 even though it does not include its own active transmitter circuit.

When it is required for the interrogator circuit 34 to talk to the tag 30 the signal 28 can be modulated by modulating the drain-source current I_{ds} of the FET 8. Modulation of the drain-source current modulates the reflection gain of the FET 8 which in turn modulates the magnitude of the signal 28. It will be appreciated however that other methods of modulating the signal may be used within the scope of the preset invention.

It is found that a high conversion gain efficiency is obtained when the reflection coefficient of the antenna 4 is low. This is achieved by arranging the circuit such that the frequency of oscillation is determined by the resonant frequency of the antennae. The frequency of self oscillation of the circuit is primarily determined by the point at which the net phase shift between the FET 8 and the antenna 4 is zero degrees and where the reflection gain of the FET 8 exceeds the return loss of the antenna 4. The frequency of operation of the circuit is thus determined by (more particularly controlled by) the resonant frequency of the antenna 8. By operating the circuit in this way eliminates the need for any form of frequency stabilization which would require high Q devices, such as a dielectric resonator, thereby simplifying the circuit greatly. Furthermore by operating the circuit such that its frequency of operation is controlled the resonant frequency of the antenna this ensures the FET 8 reflection gain remains high when it is in its stable oscillatory state since the return loss of the antenna is low at its resonant frequency. As the FET reflection gain remains high this ensures that the magnitude of the detected signal appearing at the output 40 is high.

In a preferred embodiment of the invention a fine tuning circuit 42 is provided to enable the frequency of operation to be accurately set. In the circuit shown in FIG. 1 the fine tuning circuit 42 comprises; a resistor 44, a capacitor 46, a diode 48 and the patch antenna 4 includes an additional element 50. The capacitor 46 and diode 48 are connected in series between the element 50 and a point at ground potential. The resistor 42 is connected between a point at a bias voltage, v_{bias} and the point of connection of the capacitor 46 and diode 48. In operation, adjusting the bias voltage will change the capacitance of the diode 48 which will affect the proportion of the radio frequency signal flowing to ground. This will change the effective length of the antenna which determines the resonant frequency of the antenna and hence the frequency of operation of the circuit.

For the embodiment illustrated effect communication with a tag 30 over a number of metres, ten metres, is possible. The power consumption of the circuit is very low as typically the current consumption is of the order of a couple of milliamperes, and this enables the interrogator 2 to be operated from a battery supply for a long operating life. In contrast, known interrogator circuits consume a few

hundred milliamperes. A further advantage of the invention is the reduced circuitry and associated costs. For example, for the embodiment illustrated the physical dimension of circuit are about a twentieth of those of known interrogator circuits with a similar performance. Such a reduction in size is important in many applications, for example cordless telephones.

It will be appreciated that modification to the circuit illustrated may be made within the scope of the invention. For example whilst a FET **8** is shown other forms of transistors may be used for example a bipolar transistor depending on the required frequency of operation. Likewise the precise details of the networks **6, 12, 14** can be tailored to suit the required frequency of operation. Furthermore the demodulated output **40** could be derived from the current flow at the drain d of FET **8** or other forms of detection may be used.

What I claim is:

1. A radio interrogator circuit for use with a transponder of a type which reflectively modulates a received radio signal, the interrogator circuit comprising:

a transistor;

an antenna connected to an input of the transistor; and

means for operating the transistor as a reflection amplifier such that it self oscillates and radiates a radio signal from the antenna and simultaneously operates as a mixer to produce an output which is representative of the modulation of a radio signal received by the antenna which has been reflectively modulated by the transponder and wherein the frequency of oscillation of the transistor is determined by the resonant frequency of the antenna.

2. An interrogator circuit according to claim **1** and further comprising means for setting the resonant frequency of the antenna.

3. An interrogator circuit according to claim **2**, which the means for setting, sets the resonant frequency of the antenna by changing the effective length of the antenna.

4. An interrogator according to claim **3** in which the circuit is operated at microwave frequencies and in the which the antennae comprises a patch antenna.

5. An interrogator circuit according to claim **4** in which the means for setting the resonant frequency of the antenna comprises a further antenna element and means for setting what proportion of the signal received the antenna passes through the further antenna element to ground.

6. An interrogator circuit according to claim **1** in which the transistor is a field effect transistor.

7. An interrogator circuit according to claim **1** and further comprising means for modulating the signal radiated from the antenna.

8. An interrogator circuit according to claim **7** in which the transistor is a field effect transistor and in the which the input of the field effect transistor comprises the gate and wherein the means for modulating the signal radiated from the antenna is operable to modulate the drain/source current of the transistor.

9. An interrogator circuit according to claim **1** and further comprising a tuned circuit connected to an output of the transistor to detect modulation of the signal received by the antenna which has been reflectively modulated by the transponder.

10. An interrogator circuit according to claim **1** and further comprising a matching network connecting the antenna to the input of the transistor.

11. An interrogator circuit according to claim **10**, in which the matching network is configured such that the return loss of the antenna as seen from the transistor is low.

12. An interrogator circuit according to claim **11** in which the matching network comprises a micro strip line.

13. An interrogator circuit according to claim **1** in which the transistor is a bipolar transistor.

* * * * *